

# Tiny Tapeout 02 Datasheet

Project Repository

<https://github.com/TinyTapeout/tinytapeout-02>

November 24, 2022

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# Render of whole chip

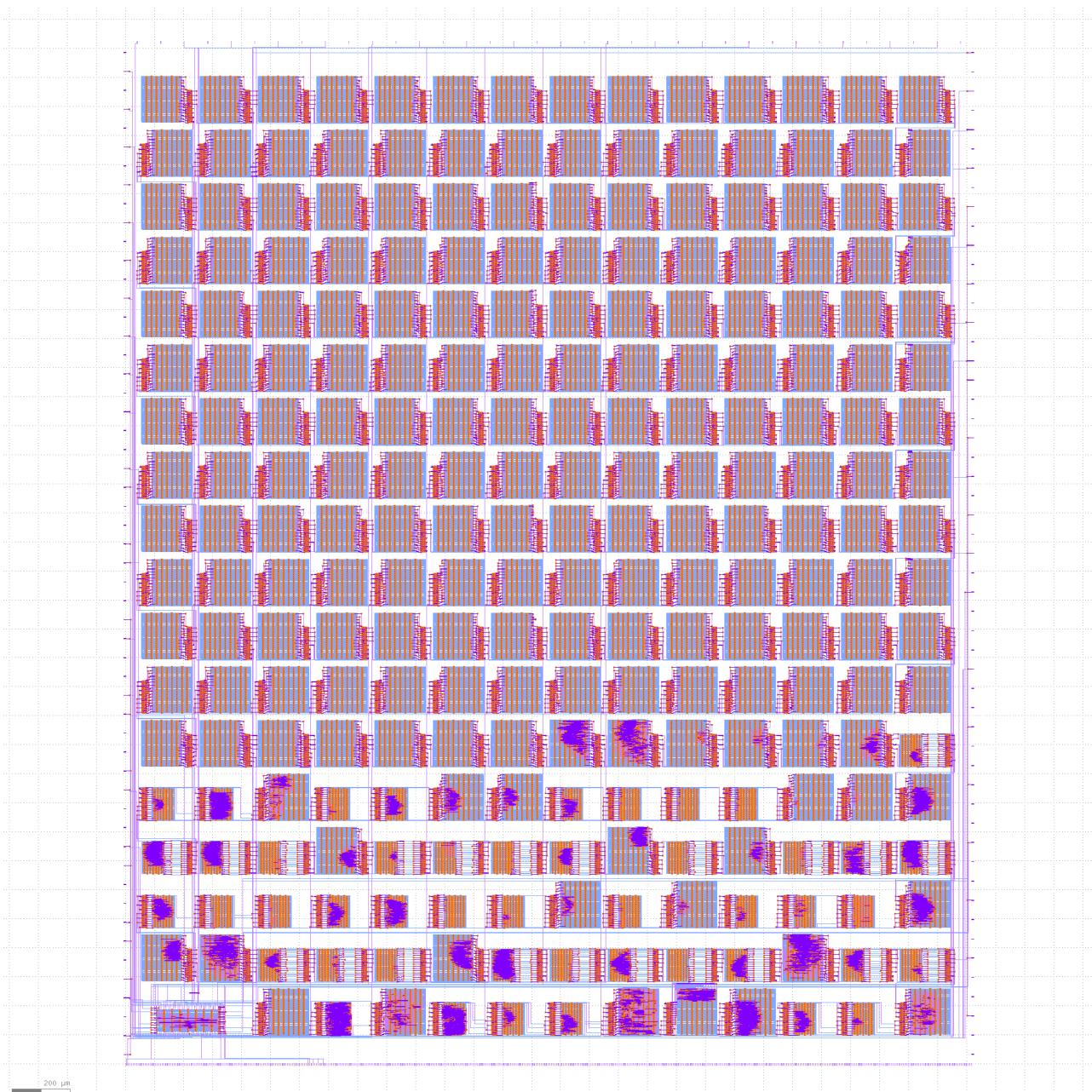


Figure 1: Full GDS

# Projects

## Test Inverter Project

- Author Matt Venn
- Description inverts every line
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware

### How it works

uses 8 inverters to invert every line

### How to test

setting the input switch to on should turn the corresponding led off

### IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	none	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

# SIMON Cipher

- Author Fraser Price
- Description Simon32/64 Encryption
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware

## How it works

Encrypts data by sending it through a feistel network for 32 rounds where it is combined with the round subkey and the last round. Data is entered into the core via shift registers.

## How to test

Set shift high and shift data in lsb first, 4 bits at a time. Shift in 96 bits, 32 being data and 64 being the key, with the plaintext being shifted in first. Eg if the plaintext was 32'h65656877 and key was 64'h1918111009080100, then 96'h191811100908010065656877 would be shifted in. Once bits have been shifted in, bring shift low, wait 32 clock cycles then set it high again. The ciphertext will be shifted out lsb first.

## IO

#	Input	Output
0	clock	data_out[0]
1	shift	data_out[1]
2	data_in[0]	data_out[2]
3	data_in[1]	data_out[3]
4	data_in[2]	segment e
5	data_in[3]	segment f
6	none	segment g
7	none	none

# HD74480 Clock

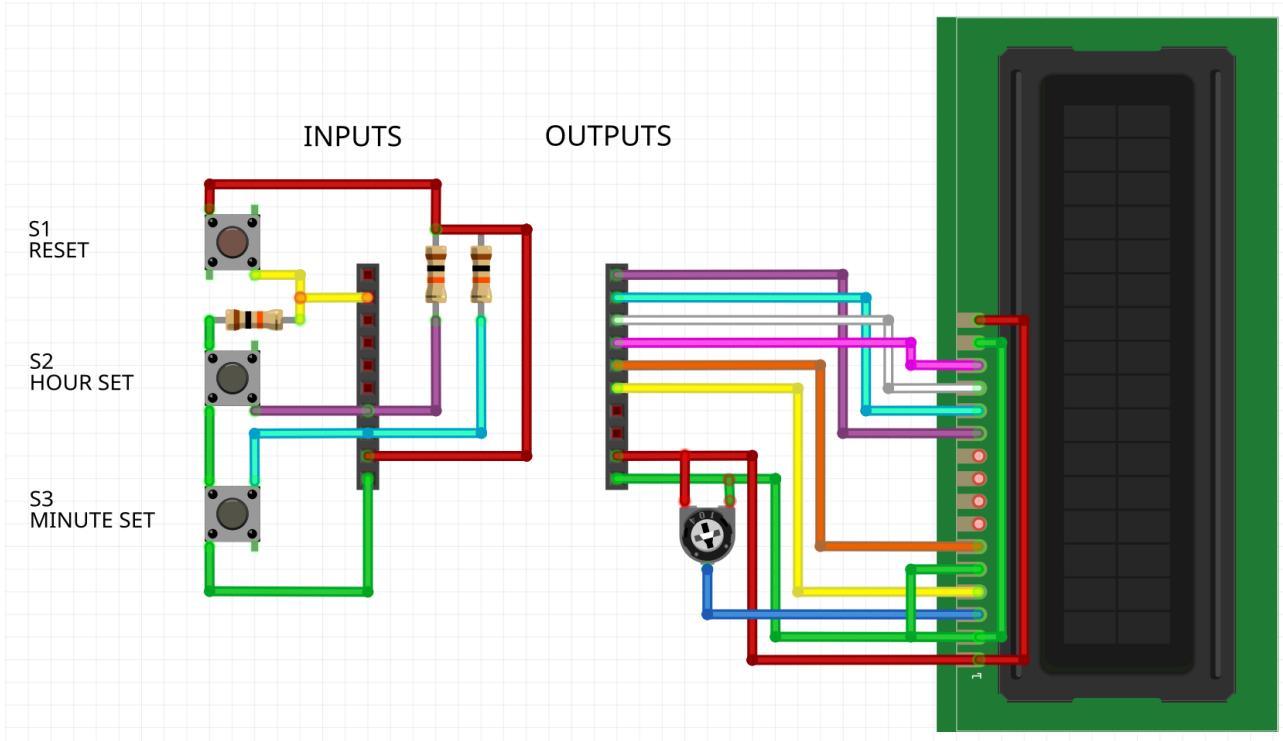


Figure 2: picture

- Author Tom Keddie
- Description Displays a clock on a attached HD74480
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware HD74480

## How it works

See <https://github.com/TomKeddie/tinytapeout-2022-2/blob/main/doc/README.md>

## How to test

See <https://github.com/TomKeddie/tinytapeout-2022-2/blob/main/doc/README.md>

## IO

#	Input	Output
0	clock	Lcd D4

#	Input	Output
1	reset	Lcd D5
2	none	Lcd D6
3	none	Lcd D7
4	none	Lcd EN
5	none	Lcd RS
6	hour set	none
7	minute set	none

## Scrolling Binary Matrix display

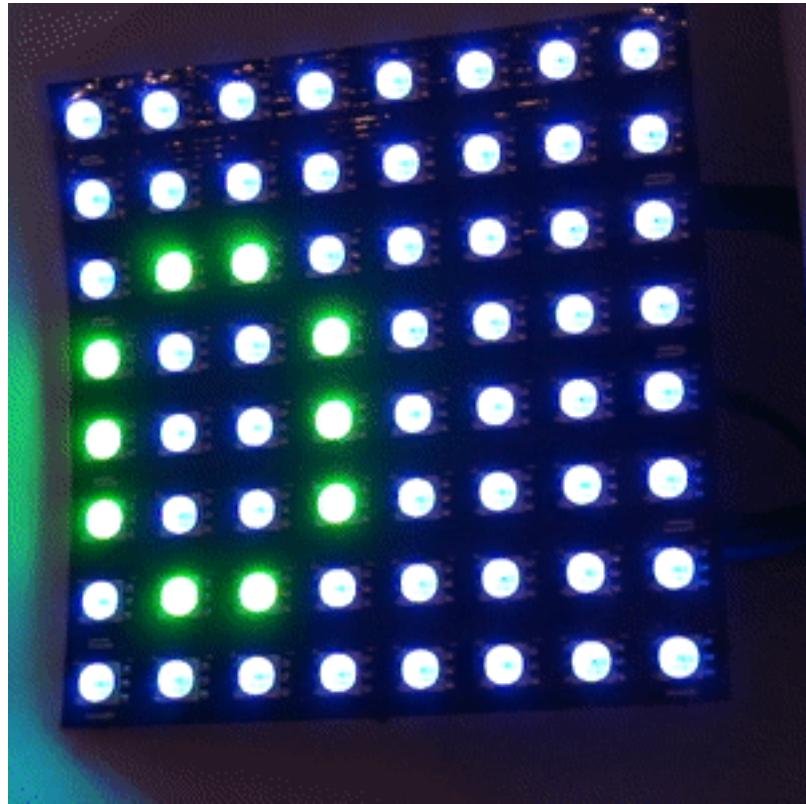


Figure 3: picture

- Author Chris
- Description Display scrolling binary data from input pin on 8x8 SK9822 LED matrix display
- GitHub repository
- HDL
- Extra docs
- Clock 6000 Hz
- External hardware Requires 8x8 matrix SK9822 LED display and 3.3V to 5V logic level shifter to convert the data and clock signals to the correct voltage for the display.

## How it works

Uses 8x8 matrix SK9822 LED display to scroll binary data as 0s and 1s in a simple font, from the input pin. Designed in verilog and tested using iCEstick FPGA Evaluation Kit. Each LED takes a 32 bit value, consisting of r,g,b and brightness.

## How to test

Need 8x8 matrix SK9822 LED display and level shifter to convert output clock and data logic to 5V logic.

## IO

#	Input	Output
0	clock	LED Clock
1	reset	LED Data
2	digit	none
3	none	none
4	none	none
5	none	none
6	none	none
7	none	none

# Power supply sequencer

- Author Jon Klein
- Description Sequentially enable and disable channels with configurable delay
- GitHub repository
- HDL
- Extra docs
- Clock 12500 Hz
- External hardware None, but could be useful for GaAs amplifiers or other circuits which need sequenced power supplies.

## How it works

Counters and registers control and track the state of channel activations. The delay input sets the counter threshold.

## How to test

After reset, bring enable high to enable channels sequentially, starting with channel 0. Bring enable low to switch off channels sequentially, starting with channel 7.

## IO

#	Input	Output
0	clock	channel 0
1	reset	channel 1
2	enable	channel 2
3	delay0	channel 3
4	delay1	channel 4
5	delay2	channel 5
6	delay3	channel 6
7	delay4	channel 7

# Duty Controller

- Author Marcelo Pouso / Miguel Correia
- Description Increase/Decrease a duty cycle of square signal.
- GitHub repository
- HDL
- Extra docs
- Clock 12500 Hz
- External hardware A 12.5Khz clock signal generator and 2 bottoms for incremental and decremental inputs. An oscilloscope to see the output PWM 1.2KHZ signal.

## How it works

Enter a square clock of 12.5Khz, and change its duty cycle by pressing increase or decrease bottom. The change will be in steps of 10%. The increase and decrease inputs have an internal debouncer that could be disabled with the input disable\_debouncer = 1.

## How to test

Connect a signal clock (io\_in[0]), reset active high signal (io\_in[1]), a button to control the incremental input (io\_in[2]) and another button to control the decremental input(io\_in[3]), and finally forced to 0 the disable\_debouncer input (io\_in[4]). The output signal will be in the pwm (io\_out[0]) port and the negate output in pwm\_neg (io\_out[1]). The signal output will have a frequency of clk/10 = 1.2Khz. When you press the incremental input bottom then the signal will increment by 10% Its duty cycle and when you press the decremental input bottom you will see that the output signal decrement by 10%.

## IO

#	Input	Output
0	clock	pwm
1	reset	pwm_neg
2	increase	increase
3	decrease	decrease
4	disable_debouncer	none
5	none	none
6	none	none
7	none	none

# S4GA: Super Slow Serial SRAM FPGA

## S4GA: Super Slow Serial SRAM FPGA

Datapath – N=283 K=3,4,5,6,7,8-LUTs I=2 O=7

*Tiny Tapeout 2, 2022-11-22*

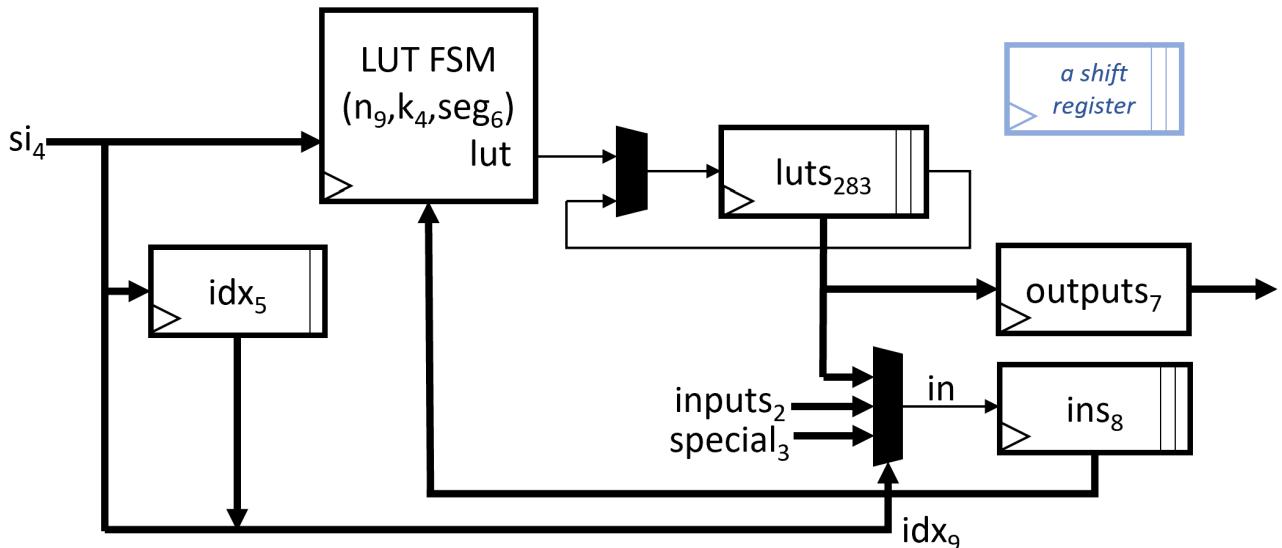


Figure 4: picture

- Author Jan Gray
- Description one fracturable 5-LUT that receives FPGA LUT configuration frames, serially evaluates LUT inputs and LUT outputs
- GitHub repository
- HDL
- Extra docs
- Clock Hz
- External hardware serial SRAM or FLASH

## How it works

The design is a single physical LUT into which an external agent pours a series of 72b LUT configuration frames, four bits per cycle. Every 18 clock cycles it evaluates a 5-input LUT. The last N=67 LUT output values are kept on die to be used as LUT inputs of subsequent LUTs. The design also has 2 FPGA input pins and 7 FPGA output pins.

## How to test

tricky

## IO

#	Input	Output
0	clk	out[0]
1	rst	out[1]
2	si[0]	out[2]
3	si[1]	out[3]
4	si[2]	out[4]
5	si[3]	out[5]
6	in[0]	out[6]
7	in[1]	debug

# ALU

- Author Ryan Cornateanu
- Description 2bit ALU with a ripple carry adder that has the capability to perform 16 different calculations
- GitHub repository
- HDL
- Extra docs
- Clock 0 Hz
- External hardware

## How it works

When 4 bits total are input'd into the ALU, it goes through 3 ripple carries and two finite state machines that adds to a temporary value that gets included in the basic ALU calculations

## How to test

TODO

## IO

#	Input	Output
0	A1	ALU_Out1
1	A2	ALU_Out2
2	B1	ALU_Out3
3	B2	ALU_Out4
4	ALU_Sel1	ALU_Out5
5	ALU_Sel2	ALU_Out6
6	ALU_Sel3	ALU_Out7
7	ALU_Sel4	CarryOut

# The McCoy 6-bit Microprocessor

- Author Aidan Good
- Description Custom RISC-V inspired microprocessor capable of simple arithmetic, branching, and jumps through a custom ISA.
- GitHub repository
- HDL
- Extra docs
- Clock None Hz
- External hardware Any source that allows for 14 GPIO pins. 8 to set the input pins, 6 to read the output pins.

## How it works

This chip contains an opcode decoder, 6-bit ALU, 7 general purpose and 3 special purpose 6-bit registers, branch target selector, and other supporting structures all connected together to make a 1-stage microprocessor

## How to test

To put the processor in a valid state, hold the reset pin high for one clock cycle. Instructions can begin to be fed into the processor at the beginning of the next cycle when reset is set low. When the clock signal is high, the PC will be output. When the clock signal is low, the x8 register will be output. There are example programs in the testbench folder and a more thorough explanation in the project readme.

## IO

#	Input	Output
0	clk	out0
1	reset	out1
2	in0	out2
3	in1	out3
4	in2	out4
5	in3	out5
6	in4	N/A
7	in5	N/A

## binary clock

- Author Azdle
- Description A binary clock using multiplexed LEDs
- GitHub repository
- HDL
- Extra docs
- Clock 200 Hz
- External hardware This design expects a matrix of 12 LEDs wired to the outputs. The LEDs should be wired so that current can flow from column to row. Optionally, a real time clock or GPS device with PPS output may be connected to the pps pin for more accurate time keeping. If unused this pin must be pulled to ground.

## How it works

Hours, minutes, and seconds are counted in registers with an overflow comparison. An overflow in one, triggers a rising edge on the input of the successive register. The values of each register are connected to the input to a multiplexer, which is able to control 12 LEDs using just 7 of the outputs. This design also allows use of the PPS input for more accurate time keeping. This input takes a 1 Hz clock with a rising edge on the start of each second. The hours[4:0] inputs allow setting of the hours value displayed on the clock when coming out of reset. This can be used for manually setting the time, so it can be done on the hour of any hour. It can also be used by an automatic time keeping controller to ensure the time is perfectly synced daily, for instance at 03:00 to be compatible with DST.

## How to test

After reset, the output shows the current Hours:Minutes that have elapsed since coming out of reset, along with the 1s bit of seconds, multiplexed across the rows of the LED array. The matrix is scanned for values: rows[2:0] = 4'b110; cols[3:0] = 4'bMMMS; rows[2:0] = 4'b101; cols[3:0] = 4'bHHMM; rows[2:0] = 4'b011; cols[3:0] = 4'bHHHH;

(M: Minutes, H: Hours, x: Unused) Directly out of reset, at 0:00, a scan would be: rows[2:0] = 4'b110; cols[3:0] = 4'b0000; rows[2:0] = 4'b101; cols[3:0] = 4'b0000; rows[2:0] = 4'b011; cols[3:0] = 4'b0000;

After one second, at 00:00:01, a scan would be: rows[2:0] = 4'b110; cols[3:0] = 4'b0001; rows[2:0] = 4'b101; cols[3:0] = 4'b0000; rows[2:0] = 4'b011; cols[3:0] = 4'b0000;

After one hour and two minutes, at 1:02, a scan would be: rows[2:0] = 4'b110; cols[3:0] = 4'b0110; rows[2:0] = 4'b101; cols[3:0] = 4'b0100; rows[2:0] = 4'b011; cols[3:0] =

4'b0000;

The above can be sped up using the PPS (Pulse Per Second) input, as long as the PPS pulses are kept to 1 pulse per 2 clock cycles or slower. The hours input can be tested by applying the binary value of the desired hour. Asserting reset for at least one clock cycle, and checking the value of hours displayed in the matrix.

## IO

#	Input	Output
0	clock	col 0
1	reset	col 1
2	pps	col 2
3	hours_b1	col 3
4	hours_b2	row 0
5	hours_b4	row 2
6	hours_b8	row 3
7	hours_b16	none

# TinySensor

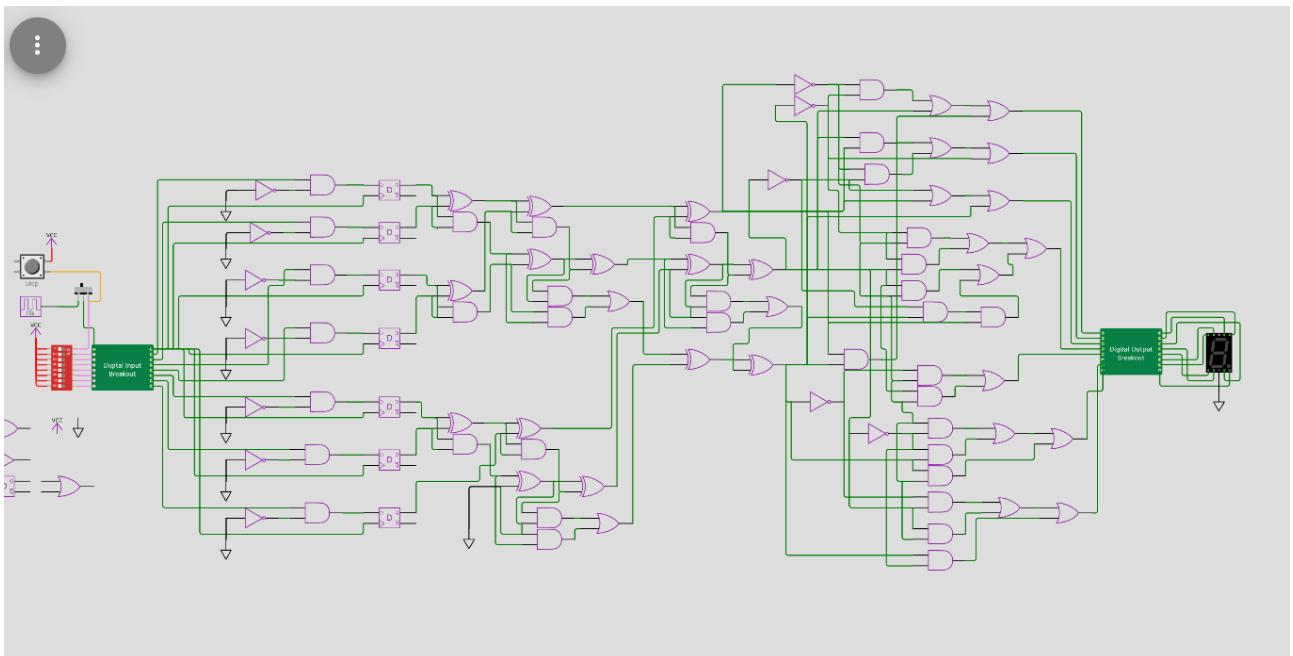


Figure 5: picture

- Author Justin Pelan
- Description Using external hardware photodiodes as inputs, display light intensity on the 7-segment display
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware Breadboard, resistors, photodiodes, specific part# TBD

## How it works

Inputs 1-6 will be connected to external photodiodes to read either a '0' or '1', inputs will be added together and displayed on the 7-segment display

## How to test

Dip switches 1-6 can be used instead of external hw to provide inputs, and 7 is used to switch between Step or Continuous sample mode. Throw the switches and the total number should show up on the 7-segment display

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	none	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

# 16x8 SRAM & Streaming Signal Generator

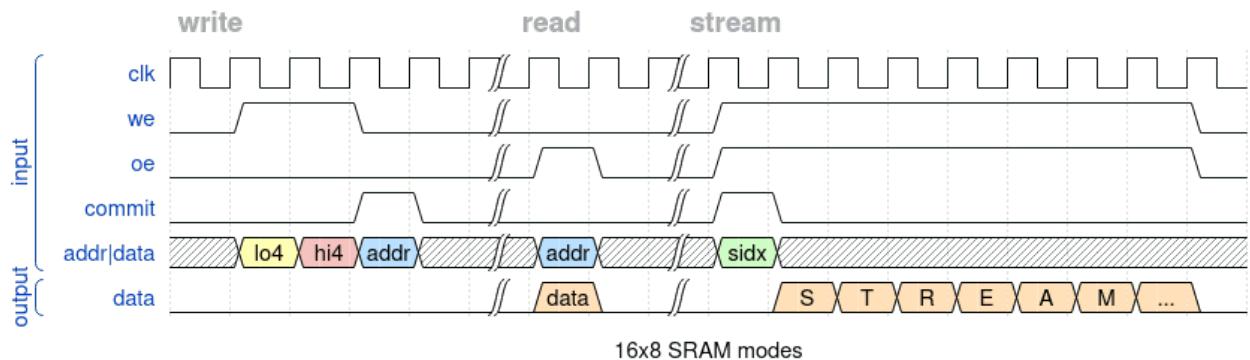


Figure 6: picture

- Author James Ross
- Description Write to, Read from, and Stream 16 addressable 8-bit words of memory
- GitHub repository
- HDL
- Extra docs
- Clock 0 Hz
- External hardware

## How it works

*WRITE MODE:* Write Enable (WE) pin high while passing 4-bits low data, 4-bits high data into an 8-bit temporary shift register. After loading data into the temporary shift register, setting Commit high while passing a 4-bit address will place the register value into memory. Fast memset, such as zeroing memory, can be performed with Commit high while passing a new address per clock cycle. *READ MODE:* While Output Enable (OE) high, a 4-bit address will place the data from memory into the temporary register returns 8-bit register to output data interface. *STREAM MODE:* While WE, OE, and Commit high, pass the starting stream index address. Then, while WE and OE are both high, the output cycles through all values in memory. This may be used as a streaming signal generator.

## How to test

After reset, you can write values into memory and read back. See the verilator test-bench.

## IO

#	Input	Output
0	clk	data[0]
1	we	data[1]
2	oe	data[2]
3	commit	data[3]
4	addr[0]/high[0]/low[0]	data[4]
5	addr[1]/high[1]/low[1]	data[5]
6	addr[2]/high[2]/low[2]	data[6]
7	addr[3]/high[3]/low[3]	data[7]

# German Traffic Light State Machine

- Author Jens Schleusner
- Description A state machine to control german traffic lights at an intersection.
- GitHub repository
- Wokwi
- Extra docs
- Clock 1 Hz
- External hardware An additional inverter is required to generate the pedestrian red signals from the green output. Hookup your own LEDs for the signals.

## How it works

A state machine generates signals for vehicle and pedestrian traffic lights at an intersection of a main street and a side street. A blinking yellow light for the side street is generated in the reset state.

## How to test

Provide a clock, hook up LEDs and generate a reset signal to reset the intersection to all-red. If you leave the reset signal enabled, a blinking yellow light is shown for the side street.

## IO

#	Input	Output
0	clock	main street red
1	reset	main street yellow
2	none	main street green
3	none	main street pedestrian green
4	none	side street red
5	none	side street yellow
6	none	side street green
7	none	side street pedestrian green

## 4-spin Ising Chain Simulation

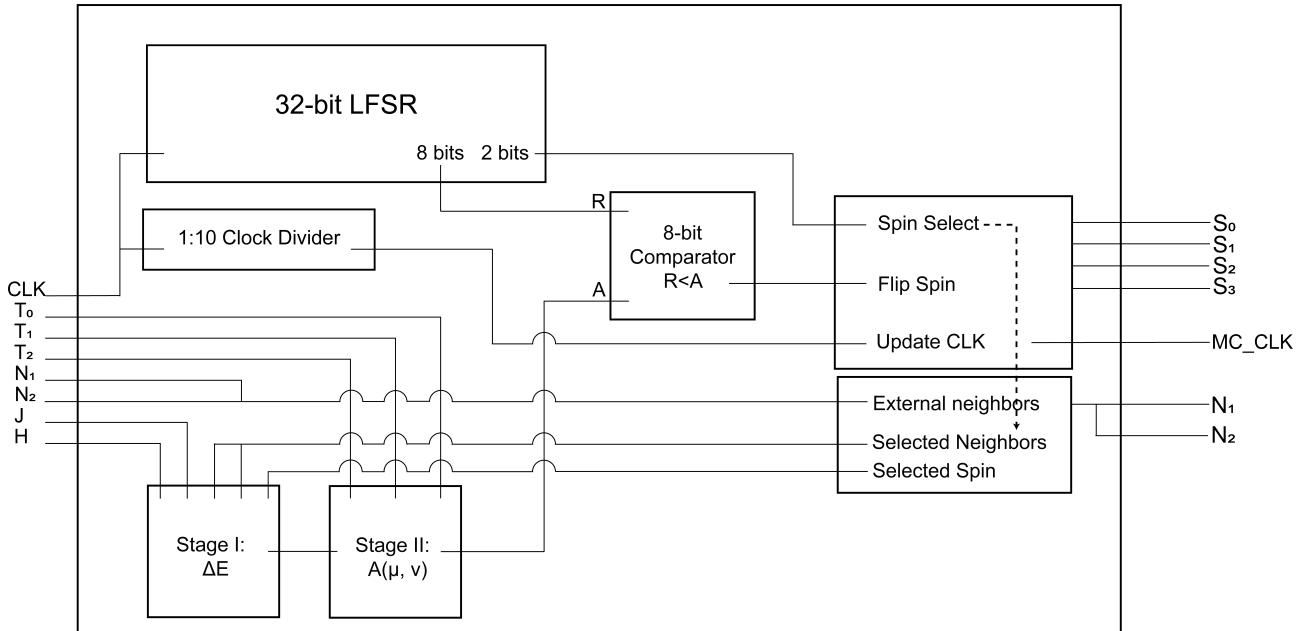


Figure 7: picture

- Author Seppe Van Dyck
- Description A self-contained physics simulation. This circuit simulates 4 spins of an Ising chain in an external field.
- GitHub repository
- Wokwi
- Extra docs
- Clock 20 Hz
- External hardware None

### How it works

It runs the Metropolis-Hastings monte-carlo algorithm to simulate 4 Ising spins in a linear chain with two external neighbours and an external field. Every monte-carlo step (10 clock cycles) a random number is created through a 32-bit LFSR and is compared to an 8-bit representations of the acceptance probability of a random spin flip. Using the inputs for external neighbors,  $N$  of these circuits can be chained together to create a  $4N$  spin Ising chain.

### How to test

The design can be tested by enabling one of the neighbours (input 4 or 5) and leave all other inputs low, the system will evolve into a ground state with every other spin pointing up.

## IO

#	Input	Output
0	clock, clock input.	segment a, Spin 0.
1	T0, LSB of the 3-bit temperature representation.	segment b, Spin 1.
2	T1, Middle bit of the 3-bit temperature.	segment c, Spin 2.
3	T2, MSB of the 3-bit temperature.	segment d, Spin 3.
4	N1, Value of neighbour 1 (up/1 or down/0).	segment e, Neighbour 2.
5	N2, Value of neighbour 2 (up/1 or down/0).	segment f, Neighbour 1.
6	J, The sign of the NN coupling constant J.	none
7	H, Value of the coupling to the external field H.	segment h, MC Step Indicator.

# Avalon Semiconductors '5401' 4-bit Microprocessor

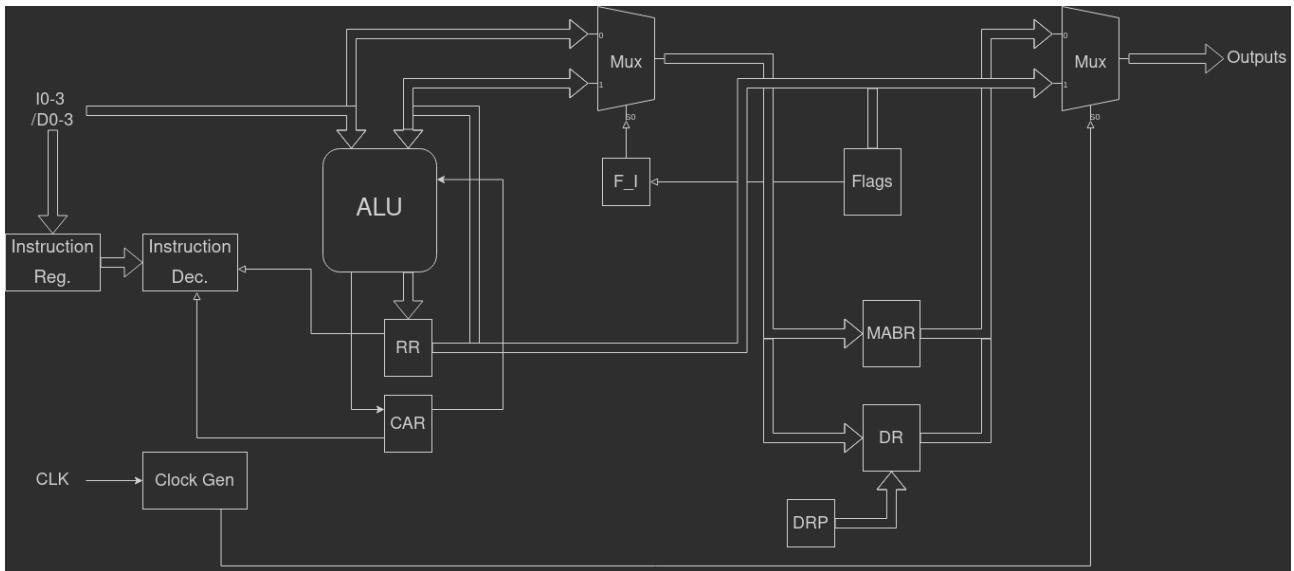


Figure 8: picture

- Author Tholin
- Description 4-bit CPU capable of addressing 4096 bytes program memory and 254 words data memory, with 6 words of on-chip RAM and two general-purpose input ports. Hopefully capable of more complex computation than previous CPU submissions.
- GitHub repository
- HDL
- Extra docs
- Clock 6000 Hz
- External hardware At the very minimum a program memory, and the required glue logic. See "Example system diagram" in the full documentation.

## How it works

The chip contains a 4-bit ALU, a 4-bit Accumulator, 8-bit Memory Address Register and 12-bit "Destination Register", which is used to buffer branch target addresses. It also has two general-purpose input ports. The instruction set consists of 16 instructions, containing arithmetic, logical, load/store, branch and conditional branch instruction. See the full documentation for a complete architectural description.

## How to test

It is possible to test the CPU using a debounced push button as the clock, and using the DIP switches on the PCB to key in instructions manually. Set the switches to 0100\_0000 to assert RST, and pulse the clock a few times. Then, change the switches

to 0000\_1000 (SEI instruction) and pulse the clock four times. After that, set the switches to all 0s (LD instruction). Pulse the clock once, then change the switches to 0001\_0100, and pulse the clock three more times. Lastly, set the switches to 0011\_1100 (LMH instruction). If done correctly, after two pulses of the clock, the outputs will read 0101\_0000 and two more pulses after that, they will be xxxx\_1000 ('x' means don't care). This sequence should repeat for as long as you keep pulsing the clock, without changing the inputs.

## IO

#	Input	Output
0	CLK	MAR0 / DR0 / DR8 / RR0
1	RST	MAR1 / DR1 / DR9 / RR1
2	I0 / D0	MAR2 / DR2 / DR10 / RR2
3	I1 / D1	MAR3 / DR3 / DR11 / RR3
4	I2 / D2	MAR4 / DR4 / F_MAR
5	I3 / D3	MAR5 / DR5 / F_WRITE
6	EF0	MAR6 / DR6 / F_JMP
7	EF1	MAR7 / DR7 / F_I

## small FFT

- Author Rice Shelley
- Description Computes a small fft
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware

## How it works

Takes 4 4-bit signed inputs (real integer numbers) and outputs 4 6-bit complex numbers

## How to test

after reset, use the write enable signal to write 4 inputs. Read the output for the computer FFT.

## IO

#	Input	Output
0	clock	rd_idx_zero
1	reset	none
2	wrEn	data_out_0
3	none	data_out_1
4	data_in_0	data_out_2
5	data_in_1	data_out_3
6	data_in_2	data_out_4
7	data_in_3	data_out_5

# Stream Integrator

- Author William Moyes
- Description A silicon implementation of a simple optical computation
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware

## How it works

It is possible to generate a pseudorandom bit sequence optomechanically using four loops of punched paper tape. Each of the four tape loops, labeled A, B, C, and D, encodes one bit of information per linear position using a tape specific hole pattern. The patterns are TapeA\_0=X000, TapeA\_1=OX00, TapeB\_0=OOX0, TapeB\_1=OOOX, TapeC\_0=OOXX, TapeC\_1=XX00, TapeD\_0=OXOX, TapeD\_1=XOXO, where O is a hole, and X is filled. The pseudorandom sequence is obtained by physically stacking the four tapes together at a single linear point, and observing if light can pass through any of the four hole positions. If all four hole positions are blocked, a 0 is generated. If any of the four holes allows light to pass, a 1 is generated. The next bit is obtained by advancing all four tapes by one linear position and repeating the observation. By using the specified bit encoding patterns, the expression  $(C ? A : B) \wedge D$  is calculated. If all four tapes are punched with randomly chosen 1 and 0 patterns, and each tape's length is relatively prime to the other tape lengths, then a maximum generator period is obtained. This TinyTapeout-02 minimal project was inspired by the paper tape pseudorandom bit sequence generator. It implements the core  $(C ? A : B) \wedge D$  operation electrically instead of optomechanically. An extra  $\wedge E$  term is added for ease of use.

## How to test

Run through the 32 possible input patterns, and verify the expected output value is observed. Counting from 00000 to 11111, where IN0 is the LSB (i.e. Tape A), and IN4 (i.e. Extra E) is the MSB should yield the pattern: 01010011101011001010110001010011.

## IO

#	Input	Output
0	Value from Tape A	Output
1	Value from Tape B	none

#	Input	Output
2	Value from Tape C	none
3	Value from Tape D	none
4	Extra term XORed with generator output	none
5	none	none
6	none	none
7	none	none

## **tiny-fir**

- Author Tom Schucker
- Description 4bit 2-stage FIR filter
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware Arduino or FPGA

### **How it works**

Multiplies the input by the tap coefficient for each stage and outputs the sum of all stages

### **How to test**

Load tap coefficients by setting the value and pulsing 2 times, then repeat for second tap. Change input value each clock to run filter. Select signals change output to debug 00(normal) 01(output of mult 2) 10(tap values in mem) 11(output of mult 1). FIR output discards least significant bit due to output limitations

### **IO**

#	Input	Output
0	clock	fir1/mult0/tap10
1	data0/tap0	fir2/mult1/tap11
2	data1/tap1	fir3/mult2/tap12
3	data2/tap2	fir4/mult3/tap13
4	data3/tap3	fir5/mult4/tap20
5	select0	fir6/mult5/tap21
6	select1	fir7/mult6/tap22
7	loadpulse	fir8/mult7/tap23

## Configurable SR

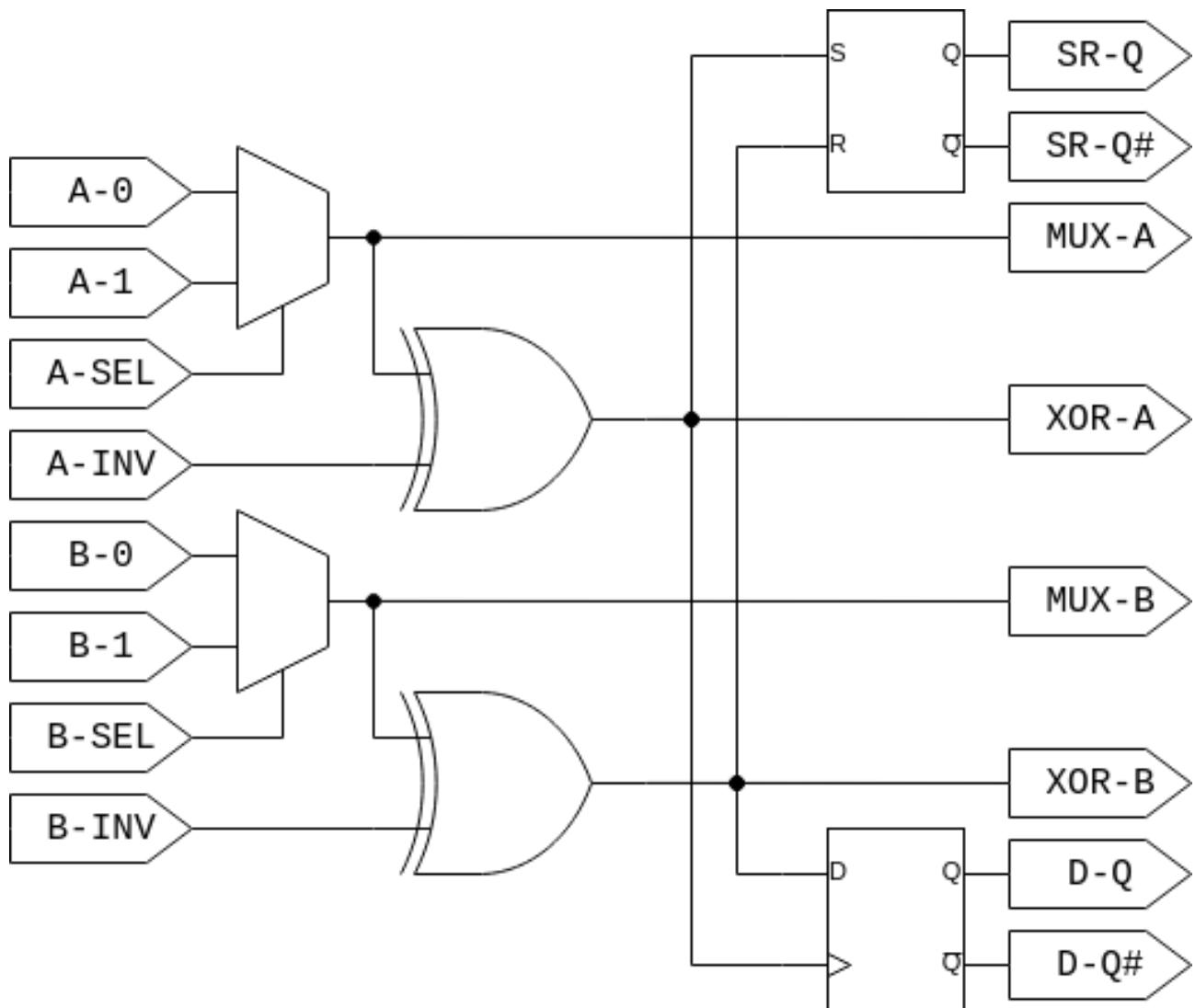


Figure 9: picture

- Author Greg Steiert
- Description Configurable gates driving SR and D flip-flops
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware none

## How it works

Two configurable gates enable a variety of complex flip-flop functions

## How to test

When SEL and INV are low, the 0 inputs directly drive the flip-flops. A-0 can be connected to the clock for use with the D flip-flop.

## IO

#	Input	Output
0	A-0	MUX-A
1	A-1	XOR-A
2	A-SEL	SR-Q
3	A-INV	D-Q
4	B-0	MUX-B
5	B-1	XOR-B
6	B-SEL	SR-Q#
7	B-INV	D-Q#

# LUTRAM

- Author Luis Ardila
- Description LUTRAM with 4 bit address and 8 bit output preloaded with a binary to 7 segments decoder, sadly it was too big for 0-F, so now it is 0-9?
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware

## How it works

uses the address bits to pull from memory the value to be displayed on the 7 segments, content of the memory can be updated via a clock and data pins, reset button will revert to default info, you would need to issue one clock cycle to load the default info

## How to test

clk, data, rst, nc, address [4:0]

## IO

#	Input	Output
0	clock	segment a
1	data	segment b
2	reset	segment c
3	nc	segment d
4	address bit 3	segment e
5	address bit 2	segment f
6	address bit 1	segment g
7	address bit 0	segment pd

## chase the beat

- Author Emil J Tywoniak
- Description Tap twice to the beat, the outputs will chase the beat. Or generate some audio noise!
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware A button on the tap input, a switch on the mode input, LEDs on the 8 outputs, and audio output on the first output. Don't just connect headphones or speakers directly! It could fry the circuit, you need some sort of amplifier.

## How it works

The second button press sets a ceiling value for the 1kHz counter. When the counter hits that value, it barrel-shifts the outputs by one bit. When the mode pin isn't asserted, the first output pin emits digital noise generated by a LFSR

## How to test

Set 1kHz clock on first input. After reset, set mode to 1, tap the tap button twice within one second. The outputs should set to the beat

## IO

#	Input	Output
0	clk	o_0 - LED or noise output
1	rst	o_1 - LED
2	tap	o_2 - LED
3	mode	o_3 - LED
4	none	o_4 - LED
5	none	o_5 - LED
6	none	o_6 - LED
7	none	o_7 - LED

# BCD to 7-segment encoder

- Author maehw
- Description Encode binary coded decimals (BCD) in the range 0..9 to 7-segment display control signals
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware Input switches and 7-segment display (should be on the PCB)

## How it works

The design has been fully generated using <https://github.com/maehw/wokwi-lookup-table-generator> using a truth table ([https://github.com/maehw/wokwi-lookup-table-generator/blob/main/demos/bcd\\_7segment\\_lut.logic.json](https://github.com/maehw/wokwi-lookup-table-generator/blob/main/demos/bcd_7segment_lut.logic.json)). The truth table describes the translation of binary coded decimal (BCD) numbers to wokwi 7-segment display (<https://docs.wokwi.com/parts/wokwi-7segment>). Valid BCD input values are in the range 0..9, other values will show a blank display.

## How to test

Control the input switches on the PCB and check the digit displayed on the 7-segment display.

## IO

#	Input	Output
0	w	segment a
1	x	segment b
2	y	segment c
3	z	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

## 4-bit Multiplier

- Author Fernando Dominguez Pousa
- Description 4-bit Multiplier based on single bit full adders
- GitHub repository
- HDL
- Extra docs
- Clock 2500 Hz
- External hardware Clock divider to 2500 Hz. Seven segment display with dot led. 8-bit DIP Switch

### How it works

Inputs to the multiplier are provided with the switch. As only eight inputs are available including clock and reset, only three bits remain available for each multiplication factor. Thus, a bit zero is set as the fourth bit. The output product is showed in the 7 segment display. Inputs are registered and a product is calculated. As output is 8-bit number, every 500ms a number appears. First the less significant 4 bits, after 500ms the most significant. When less significant 4-bits are displayed, the led dot including in the display is powered on.

### How to test

HDL code is tested using Makefile and cocotb. 4 set of tests are included: the single bit adder, the 4-bit adder, the 4-bit multiplier and the top design. In real hardware, the three less significant bits can create a number times the number created with the next three bits. Reset is asserted with the seventh bit of the switch.

### IO

#	Input	Output
0	clock	segment_1 (o_segments[0])
1	reset	segment_2 (o_segments[1])
2	i_factor_a[0]	segment_3 (o_segments[2])
3	i_factor_a[1]	segment_4 (o_segments[3])
4	i_factor_a[2]	segment_5 (o_segments[4])
5	i_factor_b[3]	segment_6 (o_segments[5])
6	i_factor_b[4]	segment_7 (o_segments[6])
7	i_factor_b[5]	segment_dot (o_lsb_digit)

# Avalon Semiconductors ‘TBB1143’ Programmable Sound Generator

- Author Tholin
- Description Sound generator with two square-wave voices, one sawtooth voice and one noise channel. Can also be used as a general-purpose frequency generator.
- GitHub repository
- HDL
- Extra docs
- Clock 6000 Hz
- External hardware Lots of resistors or some other DAC, as well as a microprocessor or microcontroller to program the 1143.

## How it works

All tone generators simply take the input clock frequency, multiplied by 256 and divides it by 16 times the generator’s divisor setting. It does this by using a ring oscillator to generate a faster internal clock to be able to generate a wider range of tones. Of course, the outputs are still only updated as fast as the scan chain allows. The output is a 6-bit digital sample, but can easily be converted to an analog signal using a resistor chain. Also uses the leftover output pins as general-purpose outputs.

## How to test

It is possible to use the DIP switches to program the generator according to the documentation. Writing 1101 into address 1, 1010 into address 2, 0000 into address 3 and finally 0001 into address 7 will cause a ~440Hz tone to appear on the output.

## IO

#	Input	Output
0	CLK	SOUT0
1	RST	SOUT1
2	D0	T0
3	D1	T1
4	D2	T2
5	D3	T3
6	A0	LED0
7	WRT	LED1

## Transmit UART

- Author Tom Keddie
- Description Transmits a async serial string on a pin
- GitHub repository
- HDL
- Extra docs
- Clock 1200 Hz
- External hardware Serial cable

### How it works

Sends an async uart message on severals pins

### How to test

Attach a uart receiver to each pins, set the baud rate to 1200 and read the messages

### IO

#	Input	Output
0	clock	uart_tx_0
1	reset	uart_tx_1
2	none	uart_tx_2
3	none	none
4	none	none
5	none	none
6	none	none
7	none	none

# RGB LED Matrix Driver

- Author Matt M
- Description Drives a simple animation on SparkFun's RGB LED 8x8 matrix backpack
- GitHub repository
- HDL
- Extra docs
- Clock 6250 Hz
- External hardware RGB LED matrix backpack from SparkFun: <https://www.sparkfun.com>

## How it works

Implements an SPI master to drive an animation with overlapping green/blue waves and a moving white diagonal. Some 7-segment wires are used for a 'sanity check' animation.

## How to test

Wire accordingly and use a clock up to 12.5 KHz. Asynchronous reset is synchronized to the clock.

## IO

#	Input	Output
0	clock	SCLK
1	reset	MOSI
2	none	segment c
3	none	segment d
4	none	segment e
5	none	nCS
6	none	segment g
7	none	none (always high)

# Tiny Phase/Frequency Detector

- Author argunda
- Description Detect phase shifts between 2 square waves.
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware Signal generators for square wave inputs.

## How it works

This is one of the blocks of a phased locked loop. The inputs are a reference clock and feedback clock and the outputs are the phase difference on either up or /down pin.

## How to test

If the phase of the feedback clock is leading the reference clock, the up signal should show the phase difference. If it's lagging, the down signal will show the difference.

## IO

#	Input	Output
0	reference clock	up
1	feedback clock	(inverted) down
2	active-low reset	none
3	none	none
4	none	none
5	none	none
6	none	none
7	none	none

# Loading Animation

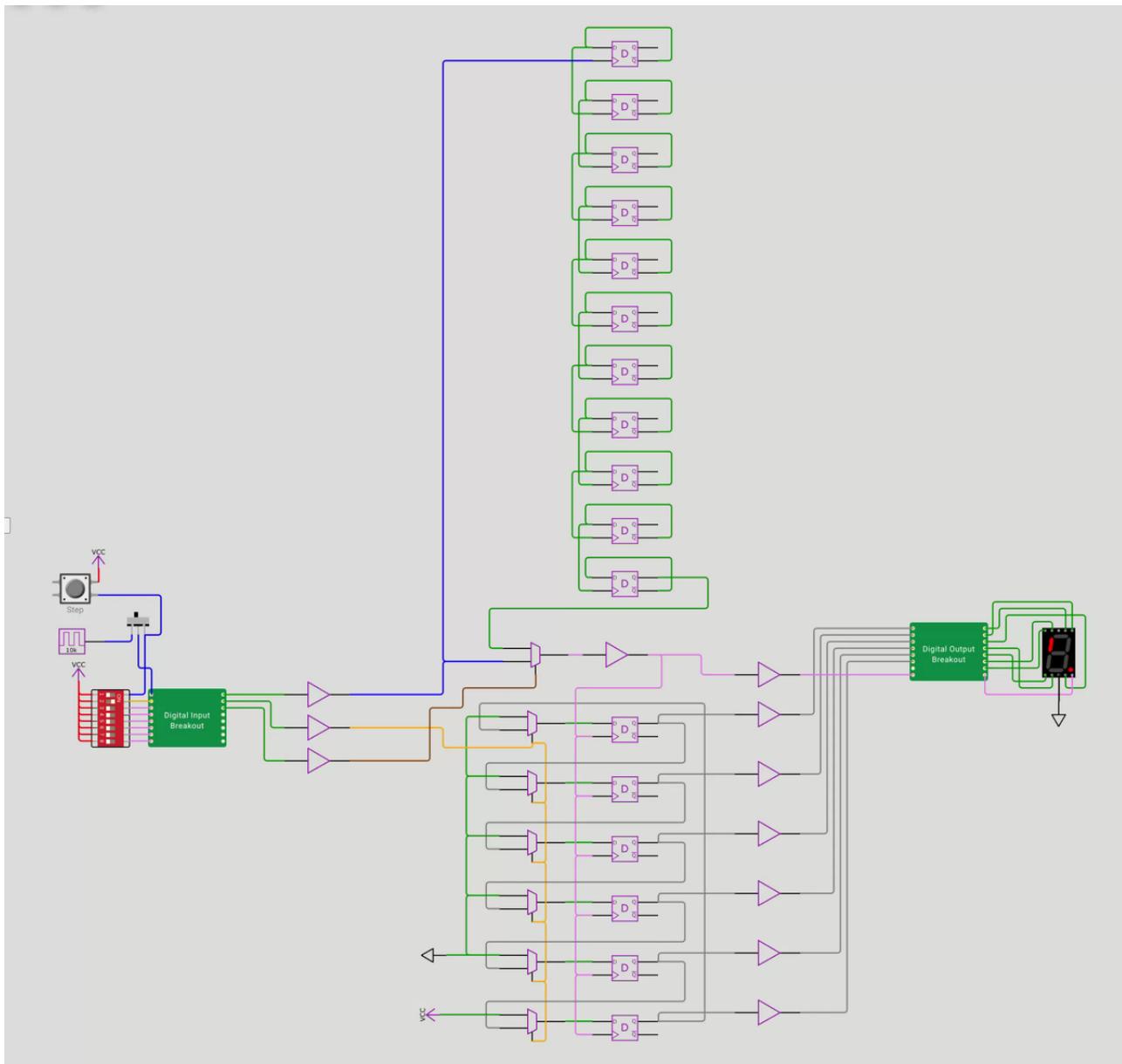


Figure 10: picture

- Author Andre & Milosch Meriac
- Description Submission for tt02 - Rotating Dash
- GitHub repository
- Wokwi
- Extra docs
- Clock 10000 Hz
- External hardware Default PCB

## How it works

Slide switch to external clock. All DIP switches to off. DIP2 (Reset) on to run (Reset is low-active). By switching DIP3 (Mode) on and setting the sliding switch to Step-Button, the Step-Button can be now used to animate step by step.

## How to test

Slide switch to external clock. All DIP switches to off. DIP2 (Reset) on to run (Reset is low-active).

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	mode	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	none
7	none	none

## **tiny egg timer**

- Author yubex
- Description tiny egg timer is a configurable small timer
- GitHub repository
- HDL
- Extra docs
- Clock 10000 Hz
- External hardware no external hw required

### **How it works**

Its a simple FSM with 3 states (Idle, Waiting and Alarm) and counters regarding clk\_cycles, seconds and minutes...

### **How to test**

Set the clock to 10kHz, set the wait time you want (in minutes) by setting io\_in[7:3], set the start switch to 1, the timer should be running, the dot of the 7segment display should toggle each second. If the time is expired, an A for alarm should be displayed. You can stop the alarm by setting the start switch to 0 again.

### **IO**

#	Input	Output
0	clock	segment a
1	reset	segment b
2	start	segment c
3	wait time in minutes [0]	segment d
4	wait time in minutes [1]	segment e
5	wait time in minutes [2]	segment f
6	wait time in minutes [3]	segment g
7	wait time in minutes [4]	dot

## Potato-1 (Brainfuck CPU)

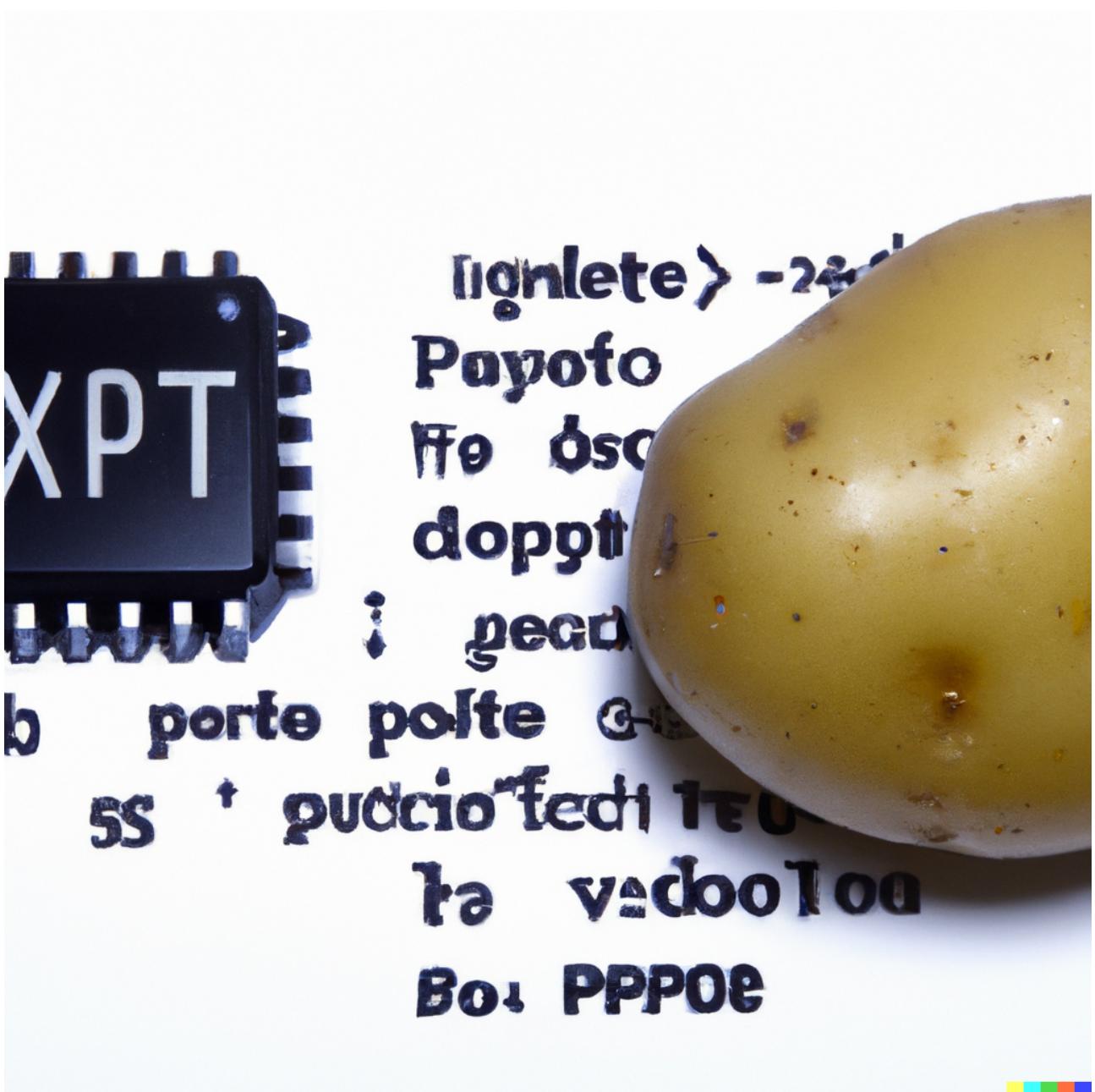


Figure 11: picture

- Author Pepper Gray (they/them)
- Description Potato-1 is part of a Brainfuck CPU. It is only the control logic, i.e. you have to bring your own registers, memory controller and io logic. It is very simple, hence likely very slow: You could probably run your brainfuck code on a potato and it would be equally fast, hence the name. The project picture was generated using DALL · E.
- GitHub repository
- HDL

- Extra docs
- Clock 12500 Hz
- External hardware Bidirectional Counter (3x)
  - program counter
  - data pointer
  - value ROM (addressed via programm counter) RAM (addressed via data pointer, all bytes must be zero after reset)

some TTL gates, e.g. to configure that the value is written to RAM every time it is changed or the data pointer is changed

## How it works

Each rising edge the CU will read in the instruction, zero flag and IO Wait flag and process it. Each falling edge the output pins will be updated. The output pins indicate which action to take, i.e. which registers to increment/decrement. If Put or Get pin is set, the CU will pause execution until IO Wait is unset. If IO Wait is already unset, the CU will immidiately execute the next command without waiting.

Additionaly to the 8 original brainfuck instructions there is a HALT instruction to stop execution and a NOP instructions to do nothing, also there are unused instruction (some of them may be used to extend the instruction set in a later itteration).

Instructions: 0000 > Increment the data pointer 0001 < Decrement data pointer 0010 + Increment value 0011 - Decrement value 0100 . Write value 0101 , Read value 0110 [ Start Loop (enter if value is non-zero, else jump to matchin ']') 0111 ] End Loop (leave if value is zero, , else jump to matchin '[') 1000 NOP No Operation 1111 HALT Halt Execution

## How to test

Reset: Set Reset\_n=0 and wait one clockcycle

Run: Set Reset\_n=1

Simple Test: - all input pins zero - clock cycle - Reset\_n high - clock cylce -> PC++ high, all outer outputs are low

Check test/test.py for small scripts to verify the CU logic

## IO

#	Input	Output
0	Clock	PC++
1	Reset_n	PC-
2	IO Wait	X++
3	Zero Flag	X-
4	Instruction[0]	A++
5	Instruction[1]	A-
6	Instruction[2]	Put
7	Instruction[3]	Get

## **heart zoe mom dad**

- Author zoe nguyen. taylor
- Description outputs my name and my age (zoe 4)
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware

## **How it works**

spells letters

## **How to test**

shift 1 hot value

## **IO**

#	Input	Output
0	Z	segment a
1	O	segment b
2	E	segment c
3	F	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

# Tiny Synth

picture

- Author Nanik Adnani
- Description A tiny synthesizer! Modulates the frequency of the clock based on inputs, plays a C scale (hopefully).
- GitHub repository
- Wokwi
- Extra docs
- Clock 12500 Hz
- External hardware Not entirely sure yet, it outputs a square wave, I still need to figure out what to do with it to make it make sound.

## How it works

Will come back and write more after my exams!

## How to test

Make sure the clock is tied to input 0, whatever frequency you want, play with it! Then you can play different notes by toggling the other inputs.

## IO

#	Input	Output
0	clock	square wave out
1	C	none
2	D	none
3	E	none
4	F	none
5	G	none
6	A	none
7	B	none

## 5-bit Galois LFSR

- Author Michael Bikovitsky
- Description 5-bit Galois LFSR with configurable taps and initial state. Outputs a value every second.
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware

### How it works

[https://en.wikipedia.org/wiki/Linear-feedback\\_shift\\_register#Galois\\_LFSRs](https://en.wikipedia.org/wiki/Linear-feedback_shift_register#Galois_LFSRs)

### How to test

1. Set the desired taps using the switches
2. Assert the reset\_taps pin
3. Deassert reset\_taps
4. Set the desired initial state
5. Assert reset\_lfsr
6. Deassert reset\_lfsr
7. Look at it go!
  - Values between 0x00-0x0F are output as hex digits.
  - Values between 0x10-0x1F are output as hex digits with a dot.

### IO

#	Input	Output
0	clock	segment a
1	reset_lfsr	segment b
2	reset_taps	segment c
3	data_in1	segment d
4	data_in2	segment e
5	data_in3	segment f
6	data_in4	segment g
7	data_in5	segment p

## **prbs15**

- Author Tom Schucker
- Description generates and checks prbs15 sequences
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware logic analyzer and jumper leads

### **How it works**

uses Lfsr to generate and check prbs15 sequence

### **How to test**

running clk, gnd pin1, set enable high. feedback prbs15 output to check, monitor error for pulses

### **IO**

#	Input	Output
0	clock	clk
1	gnd	prbs15
2	enable	error
3	check	checked
4	none	none
5	none	none
6	none	none
7	none	none

## 4-bit badge ALU

- Author Rolf Widenfelt
- Description A 4-bit ALU inspired by Supercon.6 badge
- GitHub repository
- HDL
- Extra docs
- Clock 0 Hz
- External hardware

### How it works

finite state machine with combinational logic (in verilog)

### How to test

cocotb

### IO

#	Input	Output
0	clk	none
1	rst	none
2	ctl	none
3	none	cout
4	datain3	alu3
5	datain2	alu2
6	datain1	alu1
7	datain0	alu0

# Illegal Logic

- Author James Ross
- Description This circuit logic emits a sequences of 32 hexadecimal digits to the 7 segment display which may be considered illegal in certain jurisdictions. The sequence is considered to be an illegal number.
- GitHub repository
- HDL
- Extra docs
- Clock 0 Hz
- External hardware The 7-segment display is used directly.

## How it works

There is some combinatorial logic which generates 32 numbers and then decodes those digits to the 7 segment display.

## How to test

First, raise the reset I/O (io\_in[1]) high. Then Output Enable (io\_in[2]) high for 32 cycles.

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	oe	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

## Siren

- Author Alan Green
- Description Pretty patterns and a siren straight from the 1970s
- GitHub repository
- Wokwi
- Extra docs
- Clock 12500 Hz
- External hardware For the audio output on pin 7, either use an audio amplifier or, if bravely connecting a speaker directly, place a resistor in series to limit the current.

## How it works

A long chain of D flip flops divides down the clock to produce a range of frequencies that are used for various purposes. Some of the higher frequencies are used to produce the tones. Lower frequencies are used to control the patterns of lights and to change the tones being sent to the speaker. An interesting part of the project is a counter that counts to 5 and resets to zero. This is used for one of the two patterns of lights, where the period of pattern is six.

## How to test

Connect a speaker to the last digital output pin, the one which is also connected to the decimal point on the seven segment display. Switch 8 is used to select between two groups of patterns.

## IO

#	Input	Output
0	clock	segment a
1	none	segment b
2	none	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	pattern_select	none

# YaFPGA

- Author Frans Skarman
- Description Yet another FPGA
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware

## How it works

TODO

## How to test

TODO

## IO

#	Input	Output
0	clock	output0
1	input1	output1
2	input2	output2
3	input3	output3
4	input4	none
5	config data	none
6	config clock	none
7	none	none

# M0: A 16-bit SUBLEQ Microprocessor

- Author William Moyes
- Description A capable but slow microprocessor that fits in a very tight space
- GitHub repository
- HDL
- Extra docs
- Clock 12500 Hz
- External hardware A SPI ROM and RAM for user code

## How it works

The M0 is a 16-bit, bit serial microprocessor based upon the SUBLEQ architecture. The only external devices needed for operation are a SPI RAM, SPI ROM, and clock source. The entire ROM and RAM are available for user code. All registers and logic are contained within the M0 itself. A transmit UART is included for serial output. The M0 interoperates with Oleg Mazonka's HSQ C-compiler for SUBLEQ. See <https://github.com/moyesw/TT02-M0/blob/main/README.md> for full details on the M0.

## How to test

Easy check #1 without RAM/ROM chips- Assert Reset High (input1). Hold spi\_miso low (input2). Apply a slow clock to both CLK (input0) and DBG\_in (input7). Bring Reset Low. Examine the inverted clock output on output7 (DBG\_OUT), and compare to clk on in0 to determine io scan chain quality. Examine spi\_clk on out3. There should be 40 spi clock pulses at half the clk input frequency, followed by a 2 spi clock gap where no pulses are present.

Easy check #2 without RAM/ROM chips- Assert Reset high (input2). Hold spi\_miso low. Apply a clock to CLK (input0). Bring Reset Low. Allow the M0 to reach steady state (504 clock cycles from reset). Observe the UART transmits 0xFF every 504 input clock cycles on output4. Observe that the CS0 and CS1 are accessed in the pattern: CS1, CS1, CS0, CS1, CS1, CS0. Observe that the CS0+1 and the spi\_mosi pin encodes the following repeating SPI access pattern: CS1:Rd(03):Addr(FFFE), CS1:Rd(03):Addr(FFFE), CS0:Rd(03):Addr(0000), CS1:Rd(03):Addr(FFFE), CS1:Wr(02):Addr(FFFE), CS0:Rd(03):Addr(8000). Note Each access will be accompanied by 16/17 bits of data movement.

Running code with RAM/ROM chips- Connect a programmed SPI ROM to CS1, and a SPI RAM to CS0. Assert Reset. Power up the ASIC and provide a clock. Lower Reset, and observe execution. The program's serial output will appear on output pin 4 at a baud rate that is one half the input clock frequency. See <https://github.com/moyesw/TT02-M0/blob/main/README.md> for information on

external connections, ROM and RAM data formats, instruction set, and compiler usage.

## IO

#	Input	Output
0	clk	spi_cs0
1	rst	spi_cs1
2	spi_miso	spi_clk
3	none	spi_mosi
4	none	uart_tx
5	none	none
6	none	none
7	dbg_in	dbg_out

## bitslam

- Author Jake “ferris” Taylor
- Description bitslam is a programmable sound chip with 2 LFSR voices.
- GitHub repository
- HDL
- Extra docs
- Clock 6000 Hz
- External hardware A 4-bit DAC connected to the four digital output pins.

## How it works

bitslam is programmed via its register write interface. A register write is performed by first writing an internal address register, which selects which register will be written to, and then writing a value. Bit 1 distinguishes address writes (0) or data writes (1). Address bits 1-2 address different internal modules: 00 addresses voice 0, 01 addresses voice 1, and 10 addresses the mixer. Address bit 0 addresses a register in the internal module. Each voice is controlled by a clock divider and a tap mask for the LFSR state. The clock divider is at address 0 and controls the rate at which the LFSR is updated, effectively controlling the pitch. Since bitslam is (expected to be) clocked at 6khz, the pitch will be determined by  $3\text{khz} / x$  where  $x$  is the 6-bit clock divider value. Each voice also contains a 4-bit LFSR tap mask (address 1) which determines which of 4 LFSR bits are XOR'd together to determine the new LFSR LSB. The LFSR is 10 bits wide and the tap mask bits correspond to positions 1, 4, 6, and 9, respectively. The mixer has a single register to control the volume of each voice. Bits 0-2 determine voice 0 volume, and bits 3-5 determine voice 1 volume. A value of 0 means a voice is silent, and a value of 7 is full volume. Special thanks to Daniel “trilader” Schulte for pointing out a crucial interconnect bug.

## How to test

bitslam is meant to be driven and clocked by an external host, eg. a microcontroller. The microcontroller should use the register write interface described above to program the desired audio output (eg. to play a song or sound effects) and 4-bit digital audio should be generated on the 4 digital out pins.

## IO

#	Input	Output
0	clock	digital out 0
1	address/data selector	digital out 1
2	address/data 0	digital out 2

#	Input	Output
3	address/data 1	digital out 3
4	address/data 2	none
5	address/data 3	none
6	address/data 4	none
7	address/data 5	none

# 8x8 Bit Pattern Player

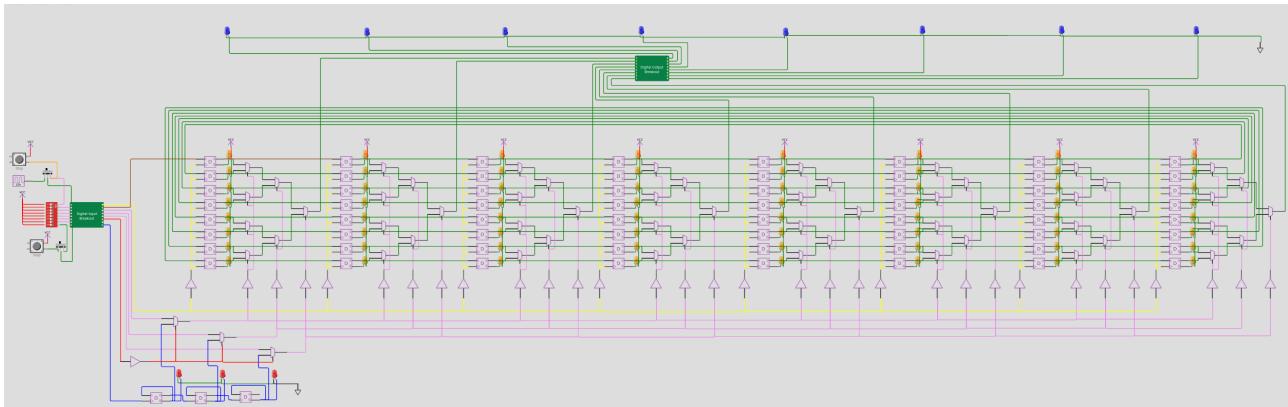


Figure 12: picture

- Author Thorsten Knoll
- Description 8x8 bit serial programmable, addressable and playable memory.
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware You could programm, address and play the 8x8 Bit Pattern Player with a breadboard, two clock buttons and some dipswitches on the input side. Add some LED to the output side. Just like the WOKWI simulation.

## How it works

The 8x8 memory is a 64-bit shiftregister, consisting of 64 serial chained D-FlipFlops (data: IN0, clk\_sr: IN1). 8 memoryslots of each 8 bit can be directly addressed via addresslines (3 bit: IN2, IN3, IN4) or from a clockdriven player (3 bit counter, clk\_pl: IN7). A mode selector line (mode: IN5) sets the operation mode to addressing or to player. The 8 outputs are driven by the 8 bit of the addressed memoryslot.

## How to test

Programm the memory: Start by filling the 64 bit shiftregister via data and clk\_sr, each rising edge on clk\_sr shifts a new data bit into the register. Select mode: Set mode input for direct addressing or clockdriven player. Address mode: Address a memoryslot via the three addresslines and watch the memoryslot at the outputs. Player mode: Each rising edge at clk\_pl enables the next memoryslot to the outputs.

## IO

#	Input	Output
0	data	bit 0
1	clk_sr	bit 1
2	address_0	bit 2
3	address_1	bit 3
4	address_2	bit 4
5	mode	bit 5
6	none	bit 6
7	clk_pl	bit 7

## XLS: bit population count

- Author proppy
- Description Count bits set in the input.
- GitHub repository
- HDL
- Extra docs
- Clock 0 Hz
- External hardware LEDs and resistors

### How it works

<https://graphics.stanford.edu/~seander/bithacks.html#CountBitsSetParallel>

### How to test

Pull up input bits, check that output bits represent the count.

### IO

#	Input	Output
0	bit0	count0
1	bit1	count1
2	bit2	count2
3	bit3	count3
4	bit4	count4
5	bit5	count5
6	bit6	count6
7	bit7	count7

## RC5 decoder

- Author Jean THOMAS
- Description Increment/decrement a counter with the press of an IR remote button!
- GitHub repository
- HDL
- Extra docs
- Clock 562 Hz
- External hardware Connect an IR demodulator (ie. TSOP1738) to the input pin

### How it works

Decodes an RC5 remote signal, increments the counter if the volume up button is pressed, decrements the counter if the volume down button is pressed

### How to test

After reset, point a remote to the IR receiver. Press the volume up button and the display count should increase.

### IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	IR demodulator output	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

# chiDOM

- Author Maria Chiara Molteni
- Description Chi function of Xoodoo protected at the first-order by DOM
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware

## How it works

Chi function of Xoodoo protected at the first-order by DOM

## How to test

Set on all the inputs

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	none	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

## Super Mario Tune on A Piezo Speaker

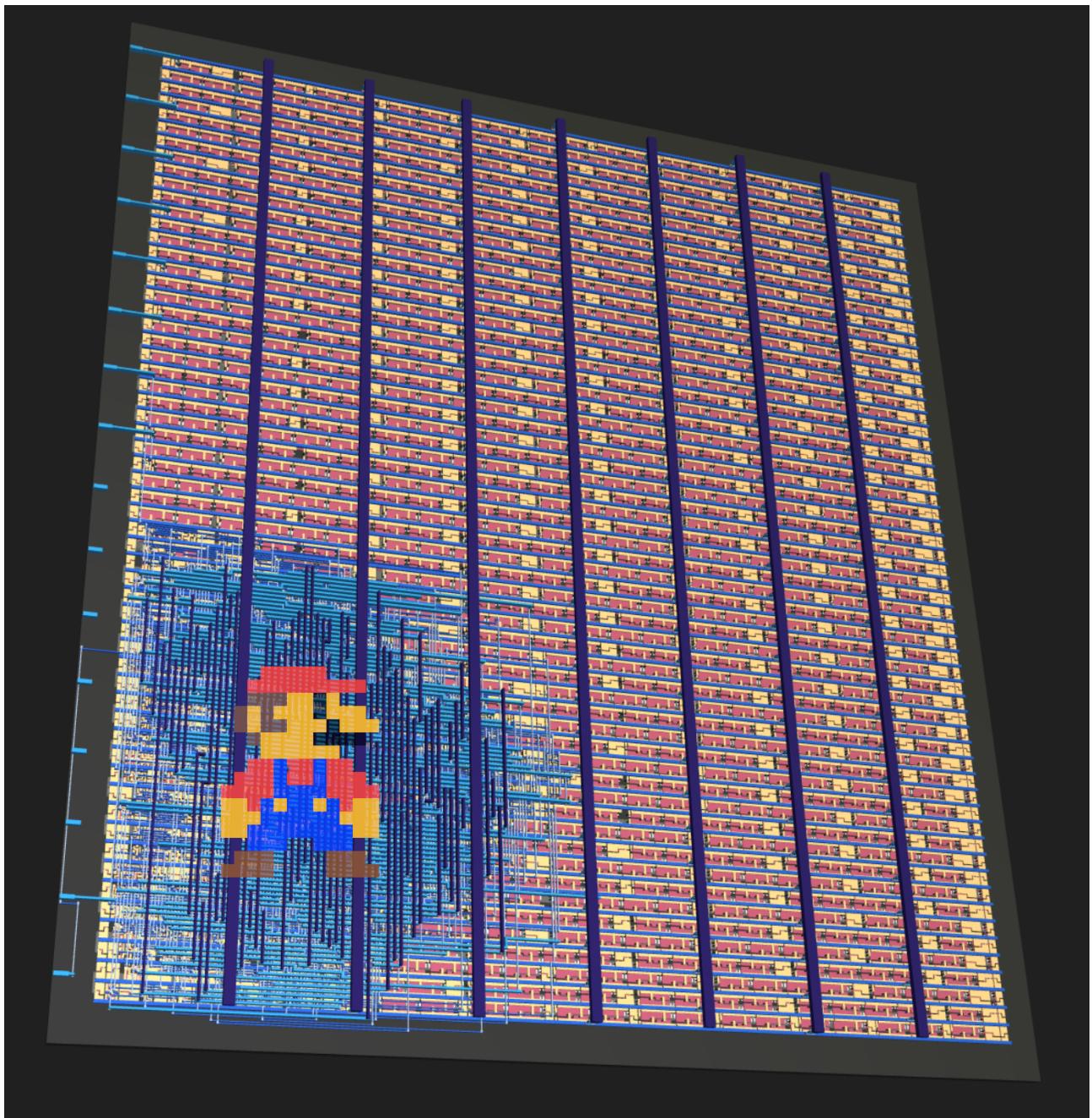


Figure 13: picture

- Author Milosch Meriac
- Description Plays Super Mario Tune over a Piezo Speaker connected across io\_out[1:0]
- GitHub repository
- HDL
- Extra docs
- Clock 3125 Hz
- External hardware Piezo speaker connected across io\_out[1:0]

## How it works

Converts an RTTL ringtone into verilog using Python - and plays it back using differential PWM modulation

## How to test

Provide 3kHz clock on io\_in[0], briefly hit reset io\_in[1] (L->H->L) and io\_out[1:0] will play a differential sound wave over piezo speaker (Super Mario)

## IO

#	Input	Output
0	clock	piezo_speaker_p
1	reset	piezo_speaker_n
2	none	none
3	none	none
4	none	none
5	none	none
6	none	none
7	none	none

## Tiny rot13

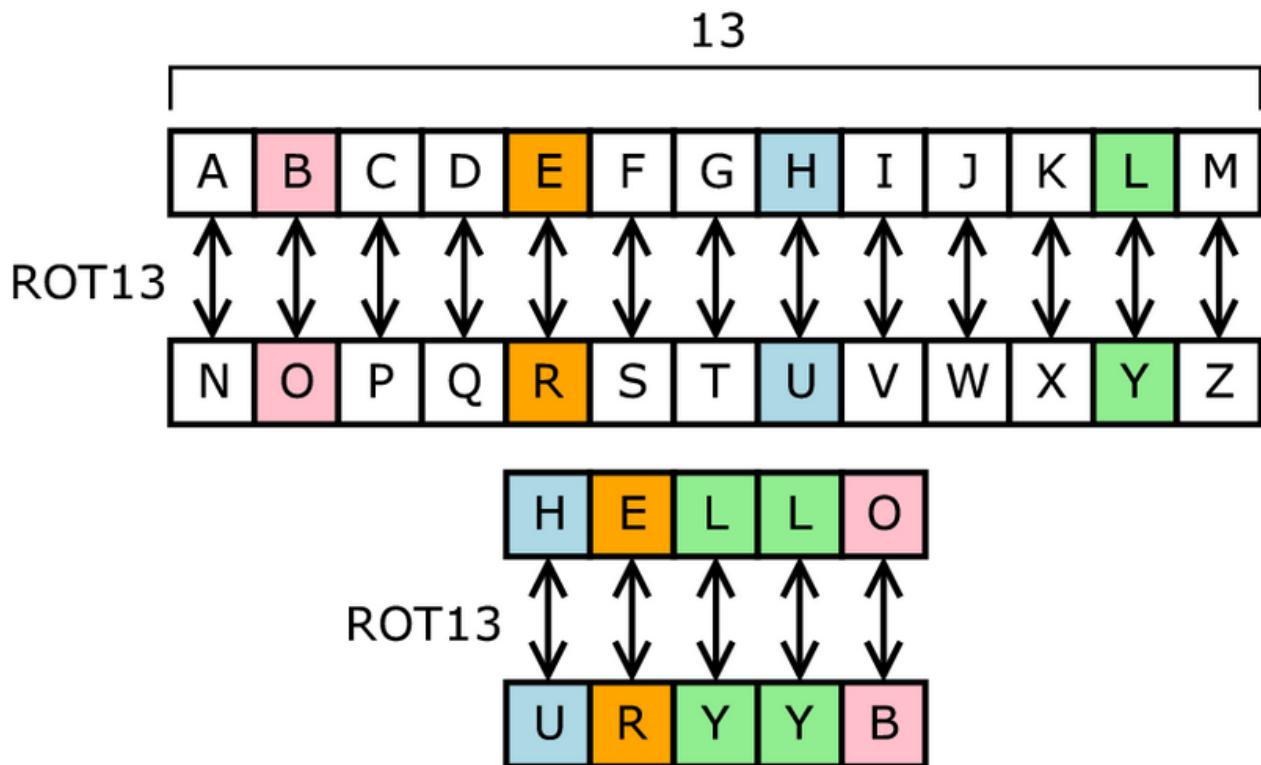


Figure 14: picture

- Author Phase Noise
- Description implements rot13 in the constraints of TT02
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware For basic usage, the carrier board should suffice. An MCU or FPGA would be required to use this to the fullest extent, and an FPGA with PCIe would let you build the world's worst ROT13 Accelerator!

## How it works

shifts in low and high nibble to construct an ASCII character, performs rot13, then outputs. The design uses some registers to store the low and high nibbles before constructing them into the ASCII character. ROT13 is implemented with a LUT generated from Python. Controlled using control lines instead of specific clock cycles. Any non-alphabetic characters are passed through

## How to test

CTL0 and CTL1 are control lines. Let CTL[1:0], 2b00 -> Shift in low nibble on D[3:0] and set output[7:0]=0x0f, 2b01 -> Shift in high nibble on D[3:0] and set output[7:0]=0xf0, 2b1X -> Shift out S on output[7:0]. Shift in the low and high nibbles of rot13, then read the result on the next cycle. Internal registers are init to 0, so by default after a RST, the output will be 0x00 for a single cycle(if CTL=2'b10), otherwise it will 2'b00 before updating to whatever the control lines set it to. Every operation effectively sets the output of the next clock cycle. Every complete operation effectively takes 4 cycles. To test, Set RST, then write 0x1 as the low nibble (clock 0), 0x4 as the high nibble (clock 1), then set the control lines to output (clock 1). 0x4e should be read at clock 4, with the output sequence being C=0 out=0x00, C=1 out=0x01, C=2 out=0x10, C=3 out=0x4e. 0x00 should produce 0x00 while 0x7f should produce 0x7f.

## IO

#	Input	Output
0	clock	D00 - LSB of output
1	reset - Resets the system to a clean state	D01
2	CTL0 - LSB of control	D02
3	CTL1 - MSB of control	D03
4	D0 - LSB of input nibble	D04
5	D1	D05
6	D2	D06
7	D3 - MSB of input nibble	D07 - MSB of output

## 4 bit counter on steamdeck

- Author 13arn
- Description copy of my tt01 submission, enable first input and press button to use the counter
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware

### How it works

fsm that uses 1 input to progress abd count from 0 to 3. Other inputs have various logic to play with

### How to test

enable first input so it is on and connected to the button. All other inputs are off. Press button to progress the fsm.

### IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	none	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

# Shiftregister Challenge 40 Bit

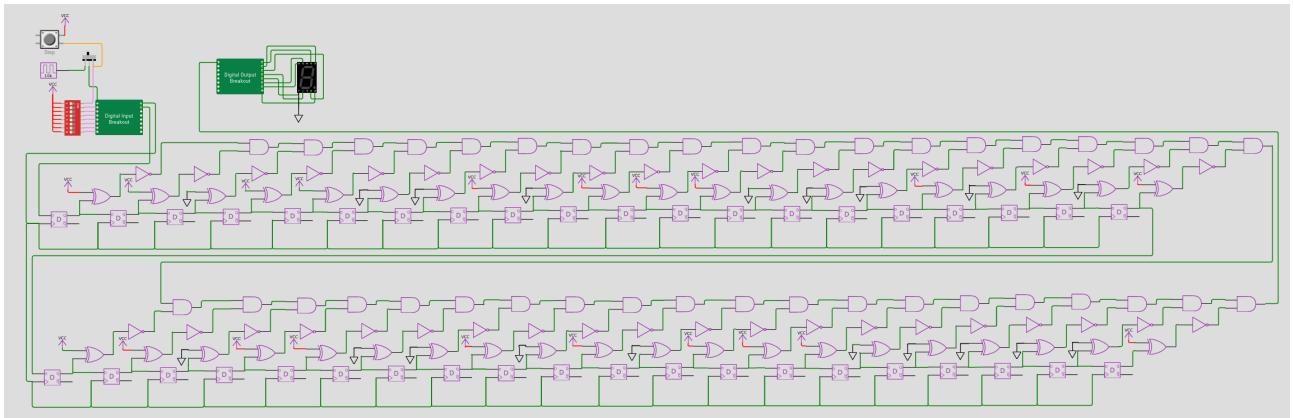


Figure 15: picture

- Author Thorsten Knoll
- Description The design is a 40 bit shiftregister with a hardcoded 40 bit number. The challenge is to find the correct 40 bit to enable the output to high. With all other numbers the output will be low.
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware To test when knowing the correct 40 bit, only a dipswitch (data), a button (clk) and a LED (output) is needed. Without knowing the number it becomes the challenge and more hardware might be required.

## How it works

Shift a 40 bit number into the chip with the two inputs data (IN0) and clk (IN1). If the shifted 40 bit match the hardcoded internal 40 bit, then and only then the output will become high. Having only the mikrochip without the design files, one might need reverse engineering and/or side channel attacks to find the correct 40 bit.

## How to test

Get the correct 40 bit from the design and shift them into the shiftregister. Each rising edge at the clk will push the next bit into the register. At the correct 40 bit, the output will enable high.

## IO

#	Input	Output
0	data	output
1	clk	none
2	none	none
3	none	none
4	none	none
5	none	none
6	none	none
7	none	none

## TinyTapeout2 4-bit multiplier.

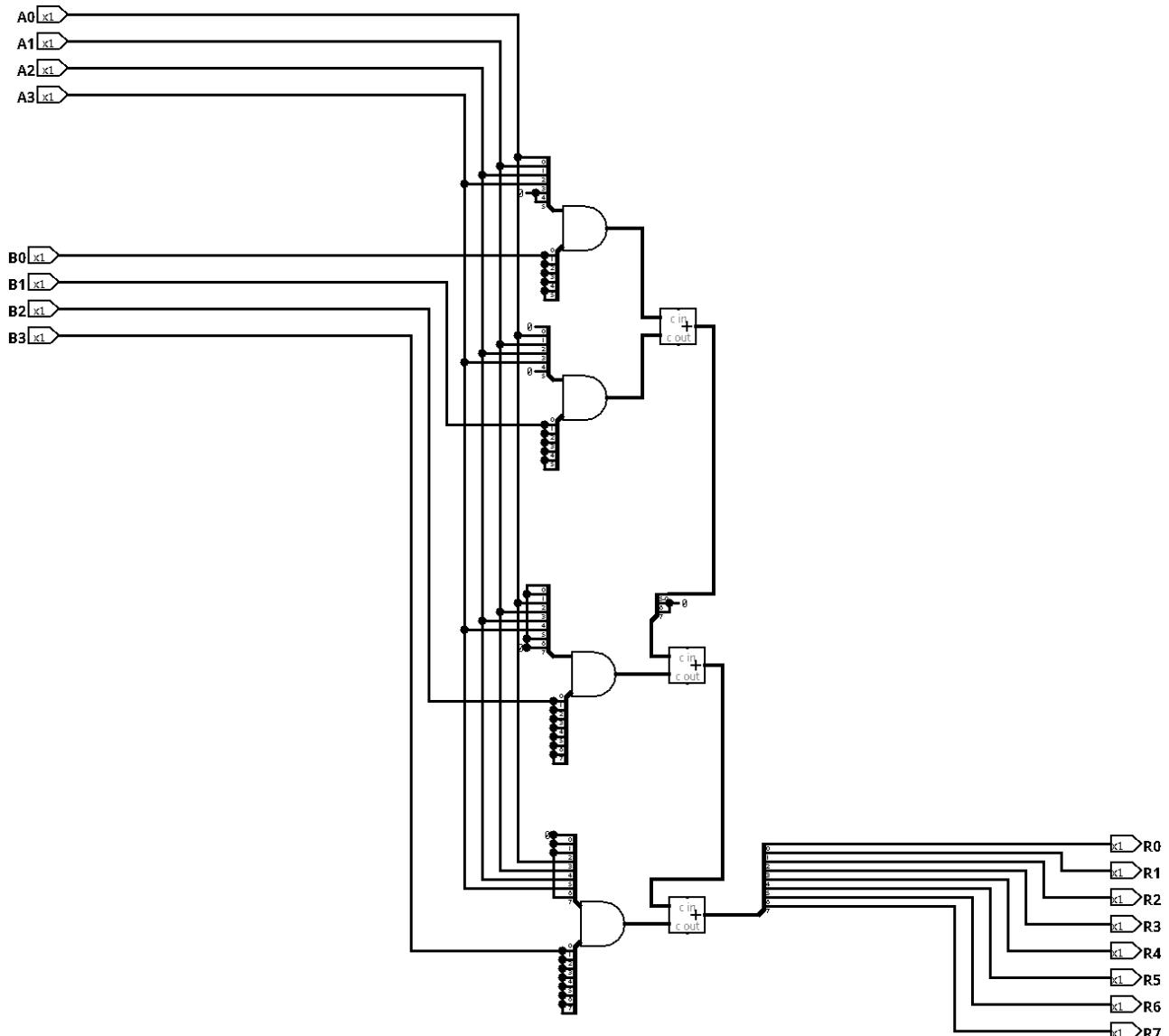


Figure 16: picture

- Author Tholin
- Description Multiplies two 4-bit numbers presented on the input pins and outputs an 8-bit result.
- GitHub repository
- HDL
- Extra docs
- Clock 6000 Hz
- External hardware DIP switches for the inputs, and LEDs on the outputs, to be able to read the binary result.

## How it works

The multiplier is implemented using purely combinatorial logic. One 6-bit adder and two 8-bit adders as well as a heap of AND gates are the only used components.

## How to test

Input any two numbers on the input ports, and check if the 8-bit result is correct.

## IO

#	Input	Output
0	A0	R0
1	A1	R1
2	A2	R2
3	A3	R3
4	B0	R4
5	B1	R5
6	B2	R6
7	B3	R7

## TinyTapeout2 multiplexed segment display timer.

- Author Tholin
- Description Measures time up to 99 minutes and 59 seconds by multiplexing 4 seven-segment displays.
- GitHub repository
- HDL
- Extra docs
- Clock 1024 Hz
- External hardware 4 seven segment displays, plus some 74-series chips to build the select logic.

### How it works

TODO

### How to test

TODO

### IO

#	Input	Output
0	CLK	A
1	RST	B
2	NC	C
3	NC	D
4	NC	E
5	NC	F
6	NC	G
7	NC	SEL

## XLS: 8-bit counter

- Author proppy
- Description Increment output bits
- GitHub repository
- HDL
- Extra docs
- Clock 10 Hz
- External hardware LEDs, pull-up/down resistors

### How it works

Implement a simple counter using [https://google.github.io/xls/tutorials/intro\\_to\\_procs/](https://google.github.io/xls/tutorials/intro_to_procs/)

### How to test

Set the reset bit once, toggle the clock once, unset the reset bit and keep toggling the clock

### IO

#	Input	Output
0	clock	count0
1	reset	count1
2	none	count2
3	none	count3
4	none	count4
5	none	count5
6	none	count6
7	none	count7

## XorShift32

- Author Ethan Mahintorabi
- Description XorShift32 random number generator
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware

### How it works

Uses the Xorshift32 algorithm to generate a random 32 bit number. Number is truncated to 3 bits and displayed

### How to test

While reset is set, hardware reads in seed value from input bits 2:7 and sets the initial seed as that binary number. After reset is deasserted, the hardware will generate a new number every 1000 clock cycles.

### IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	seed_bit0	segment c
3	seed_bit1	segment d
4	seed_bit2	segment e
5	seed_bit3	segment f
6	seed_bit4	segment g
7	seed_bit5	none

# XorShift32

- Author Ethan Mahintorabi
- Description XorShift32 random number generator
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware

## How it works

Uses the Xorshift32 algorithm to generate a random 32 bit number. Number is truncated to 3 bits and displayed

## How to test

While reset is set, hardware reads in seed value from input bits 2:7 and sets the initial seed as that binary number. After reset is deasserted, the hardware will generate a new number every 1000 clock cycles.

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	seed_bit0	segment c
3	seed_bit1	segment d
4	seed_bit2	segment e
5	seed_bit3	segment f
6	seed_bit4	segment g
7	seed_bit5	none

# Multiple Tunes on A Piezo Speaker

- Author Jiaxun Yang
- Description Plays multiple Tunes over a Piezo Speaker connected across io\_out[1:0]
- GitHub repository
- HDL
- Extra docs
- Clock 10000 Hz
- External hardware Piezo speaker connected across io\_out[1:0]

## How it works

Converts an RTTL ringtone into verilog using Python - and plays it back using differential PWM modulation

## How to test

Provide 10kHz clock on io\_in[0], briefly hit reset io\_in[1] (L->H->L) and io\_out[1:0] will play a differential sound wave over piezo speaker, different tunes can be selected by different tune\_sel inputs

## IO

#	Input	Output
0	clock	piezo_speaker_p
1	reset	piezo_speaker_n
2	tune_sel0	ledout_0
3	tune_sel1	ledout_1
4	none	ledout_2
5	none	ledout_3
6	none	none
7	none	none

## clash cpu

- Author Jack Leightcap
- Description tiny register machine written in clash
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware

## How it works

poorly

## How to test

encode instructions. tick clock.

## IO

#	Input	Output
0	instr 5	jump
1	instr 4	unused
2	instr 3	unused
3	instr 2	register 4
4	instr 1	register 3
5	instr 0	register 2
6	rst	register 1
7	clock	register 0

## TinyTapeout 2 LCD Nametag

- Author Tholin
- Description Echoes out a predefined text onto a 20x4 character LCD.
- GitHub repository
- HDL
- Extra docs
- Clock 100 Hz
- External hardware A 20x4 character LCD.

### How it works

Mostly just contains a ROM holding the text to be printed, and some logic to print the reset sequence and cursor position changes.

### How to test

Connect up a character LCD according to the pinout, set the clock and hit reset. Run using an extra slow clock, as there is no internal clock divider. It'll send data to the display as fast as it's able to. After that, it should initialize the display and start printing stuff.

### IO

#	Input	Output
0	CLK	RS
1	RST	E
2	NC	D4
3	NC	D5
4	NC	D6
5	NC	D7
6	NC	LED
7	NC	NC

# UART-CC

- Author Christina Cyr
- Description UART Template
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware Arduino

## How it works

You can hook this up to an arduino

## How to test

Use an arduino

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	none	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

## 3-bit 8-channel PWM driver

- Author Ivan Krasin
- Description PWM driver with 8 channels and 8 PWM levels from 0 to 1
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware

### How it works

uses a 3-bit counter to drive PWM on 8 output channels. Each channel is controlled by a dedicated 3-bit register that specifies its PWM level: 0 means always off, 1 is for 1/7 on, 5 is for 5/7 on and 7 is 7/7 (always on)

### How to test

after reset, all output pins will be low. Use set, addr and level pins to set PWM level=level0+2\*level1+4\*level2 on channel=addr0+2\*addr1+4\*addr2. The corresponding pin will start oscillating between 0 and 1 according to the clock and the set level.

### IO

#	Input	Output
0	clock	out0
1	pset	out1
2	addr0	out2
3	addr1	out3
4	addr2	out4
5	level0	out5
6	level1	out6
7	level2	out7

## LEDChaser from LiteX test

- Author Nick Østergaard
- Description This is just a small demo of synthesizing verilog from LiteX, this does not include any CPU.
- GitHub repository
- HDL
- Extra docs
- Clock 0 Hz
- External hardware

### How it works

It just implements LEDChaser from the LiteX LED core demo, where `io_in[3:7]` is duty cycle

### How to test

Add LEDs on the outputs in a straight line – or probe all signals on a scope and check that you get a ‘moving’ train of pulses.

### IO

#	Input	Output
0	clock	led a
1	reset	led b
2	pwm_width 0	led c
3	pwm_width 1	led d
4	pwm_width 2	led e
5	pwm_width 3	led f
6	pwm_width 4	led g
7	pwm_width 5	led h

## 8-bit (E4M3) Floating Point Multiplier

- Author Clive Chan
- Description 8-bit (E4M3) Floating Point Multiplier
- GitHub repository
- HDL
- Extra docs
- Clock 0 Hz
- External hardware

### How it works

A small mux in front to fill up two 8-bit buffers in halves, which feed the actual 8-bit multiplier. When ctrl0 is 0, you can clock in 4 bits from data[3:0] into the upper or lower halves of two buffers according to the values of ctrl[1] and ctrl[2]: - 00 STORE 1 LOWER - 01 STORE 1 UPPER - 10 STORE 2 LOWER - 11 STORE 2 UPPER  
The clock is intended for manual use instead of actually being driven by a clock, but it probably can work. The 8 bits in each of the two buffers are interpreted as an 8-bit floating point number. From MSB to LSB: - sign bit - exponent[3:0] - mantissa[2:0]  
These are interpreted according to an approximation of IEEE 754, i.e.  $(-1)^{\text{sign}} \times 2^{(\text{exponent} - \text{EXP\_BIAS})} \times 1.\text{mantissa}$  with the following implementation details / differences:  
- EXP\_BIAS = 7, analogous to  $2^{**(\exp-1)} - 1$  for all IEEE-defined formats  
- Denormals (i.e. exponent == 0) are flushed to zero on input and output  
- exponent = 0b1111 is interpreted as more normal numbers instead of NaN/inf, and overflows saturate to the largest representable number (0x1111111 = +/- 480.0)  
- Negative zero is interpreted as NaN instead.  
- Round to nearest even is implemented. The output 8 bits will always display the results of the multiplication of the two FP8's in the buffers, regardless of the clock.  
The module has been verified over all possible pairs of 8-bit inputs.

### How to test

```
cd src && make
```

### IO

#	Input	Output
0	clock	sign
1	ctrl0	exponent
2	ctrl1	exponent
3	ctrl2	exponent
4	data0	exponent

#	Input	Output
5	data1	mantissa
6	data2	mantissa
7	data3	mantissa

## Dice roll

- Author Tholin
- Description Will roll a random number from 1 - 6 on the 7-segment display, like a dice.
- GitHub repository
- HDL
- Extra docs
- Clock 6000 Hz
- External hardware A 7-segment-display. The one on-board the PCB will work.

## How it works

Contains a LSFR for random numbers, that constantly updates no matter if the dice is rolling or not. Pressing the 'ROLL' button will play an animation of random numbers cycling on the display, until settling on a number after a few seconds. The decimal point will light up when its done rolling.

## How to test

Reset, then pulse 'ROLL' to roll the dice as many time as you like.

## IO

#	Input	Output
0	CLK	segment a
1	RST	segment b
2	ROLL	segment c
3	NC	segment d
4	NC	segment e
5	NC	segment f
6	NC	segment g
7	NC	decimal point

# CNS TT02 Test 1

picture

- Author N. Sertac Artan
- Description First test run of CNS Lab
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware None

## How it works

Apply inputs, get outputs

## How to test

Wokwi

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	none	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

# CNS002 (TT02-Test 2)

picture

- Author N. Sertac Artan
- Description First test run of CNS Lab (second design)
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware None

## How it works

Apply inputs, get outputs

## How to test

Wokwi

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	none	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

## Test2

- Author Shaos
- Description Testing Flip-Flops
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware logic analyzer

## How it works

nothing special - just testing

## How to test

change inputs and see outputs :)

## IO

#	Input	Output
0	clock	segment a
1	D (no reset)	segment b
2	C	segment c
3	S	segment d
4	R	segment e
5	NAND1	segment f
6	NAND2	segment g
7	XOR	dot

# 7-segment LED flasher

- Author Joseph Chiu
- Description Drives 7-segment LED display, alternating between NIC and JAC
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware TTO standard switches and 7-segment display

## How it works

Master clock is fed through a prescaler with four tap-points which feeds a 4-bit ripple counter (there are 6 total bits, but the top two bits are discarded). 2:1 muxes are chained to act like a 8:1 mux for each LED segment position. As the counter runs, this results in each segment being turned on or off as needed to render the display sequence (NIC JAC ). The highest order bit is used to blink the decimal point on/off.

## How to test

IN5 and IN6 selects the clock prescaler. OUT0-OUT7 are the LED segment outputs.

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	none	segment c
3	none	segment d
4	none	segment e
5	Prescale select bit 0	segment f
6	Prescale select bit 1	segment g
7	none	segment dp

## Nano-neuron

- Author Daniel Burke
- Description minimal low vector test
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware

## How it works

bare influence field calculation GV open neurons

## How to test

clock in reference vector (some inversions), present DUT and get output

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	none	segment c
3	none	segment d
4	none	segment e
5	none	segment f
6	none	segment g
7	none	none

# SQRT1 Square Root Engine

- Author Davit Margarian (UDXS)
- Description Computes 4.2 fixed-point square root for any 7-bit integer
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware Optionally, binary to BCD converter for output

## How it works

This uses Newton's method to solve sqrt in 3 cycles.

## How to test

Set a 7-bit input value and toggle clock 3 times. After, the output will be correct, rounded down to the nearest 4th.

## IO

#	Input	Output
0	clock	frac1
1	i1	frac2
2	i2	whole1
3	i3	whole2
4	i4	whole3
5	i5	whole4
6	i6	none
7	i7	none

# Breathing LED

- Author argunda
- Description Use the pwm output to drive an LED and it should look like it's breathing.
- GitHub repository
- HDL
- Extra docs
- Clock 4000 Hz
- External hardware Clock source and external LED circuit.

## How it works

A triangle wave is generated and used to determine duty cycle of pwm.

## How to test

After reset, pwm should automatically be generated. The duty counter is output for debug purposes.

## IO

#	Input	Output
0	clock	breathing_pwm
1	reset	duty[0]
2	none	duty[1]
3	none	duty[2]
4	none	duty[3]
5	none	duty[4]
6	none	duty[5]
7	none	duty[6]

# Fibonacci & Gold Code

- Author Daniel Estevez
- Description This project includes two independent designs: a design that calculates terms of the Fibonacci sequence and displays them in hex one character at a time on a 7-segment display, and a Gold code generator that generates the codes used by CCSDS X-band PN Delta-DOR.
- GitHub repository
- HDL
- Extra docs
- Clock 0 Hz
- External hardware No external hardware is needed

## How it works

The Fibonacci calculator uses 56-bit integers, so the terms of the Fibonacci sequence are displayed using 7 hex characters. Since the TinyTapeout PCB only has one 7-segment display, the terms of the Fibonacci sequence are displayed one hex character at a time, in LSB order. The dot of the 7-segment display lights up whenever the LSB is being displayed. On each clock cycle, 4-bits of the next Fibonacci term are calculated using a 4-bit adder, and 4-bits of the current term are displayed in the 7-segment display. The 7-segment display is ANDed with the project clock, so that the digits flash on the display. The Gold code generator computes a CCSDS X-band PN Delta-DOR Gold code one bit at a time using LFSRs. The output bit is shown on the 7-segment display dot. 6-bits of the second LFSR can be loaded in parallel using 6 project inputs in order to be able to generate different sequences. One of the project inputs is used to select whether the 7-segment display dot is driven by the Fibonacci calculator or by the Gold code generator.

## How to test

The project can be tested by manually driving the clock using a push button or switch. Just by de-asserting the reset and driving the clock, the digits of the Fibonacci sequence terms should appear on the 7-segment display. The output select input needs to be set to Gold code (high level) in order to test the gold code generator. The load enable input (active-low), as well as the 6 inputs corresponding to the load for the B register can be used to select the sequence to generate. The load value can be set in the 6 load inputs, and then the load enable should be pulsed to perform the load. This can be done with the clock running or stopped, as the load enable is asynchronous. After the load enable is de-asserted, for each clock cycle a new bit of the Gold code sequence should appear in the 7-segment display dot.

## IO

#	Input	Output
0	clock	{‘segment a’: ‘Fibonacci hex digit’}
1	output select (high selects Gold code; low selects Fibonacci LSB marker) & Gold code load value bit 0	{‘segment b’: ‘Fibonacci hex digit’}
2	Fibonacci reset (active-low; asynchronous) & Gold code load value bit 1	{‘segment c’: ‘Fibonacci hex digit’}
3	Gold code load enable (active-low; asynchronous)	{‘segment d’: ‘Fibonacci hex digit’}
4	Gold code load value bit 2	{‘segment e’: ‘Fibonacci hex digit’}
5	Gold code load value bit 3	{‘segment f’: ‘Fibonacci hex digit’}
6	Gold code load value bit 4	{‘segment g’: ‘Fibonacci hex digit’}
7	Gold code load value bit 5	{‘none’: ‘Gold code output / Fibonacci LSB digit marker’}

## **tinytapeout2-HELLo-3orLd-7seg**



Figure 17: picture

- Author Rakesh Peter
- Description HELLo-3orLd Runner on 7 segment Display
- GitHub repository
- Wokwi
- Extra docs
- Clock 1 Hz
- External hardware

### **How it works**

BCD to 7seg Counter is modified to suit the Simplified SoP equation for each segments. See the repo for SoP computation.

### **How to test**

All toggle switches in zero position and clock switch on for auto runner. Individual BCD bits can be toggled using corresponding inputs with clock switch off.

### **IO**

#	Input	Output
0	clock	segment a
1	reset	segment b
2	none	segment c
3	dp toggle	segment d
4	BCD bit 3	segment e
5	BCD bit 2	segment f
6	BCD bit 1	segment g
7	BCD bit 0	segment dp

# Square Root

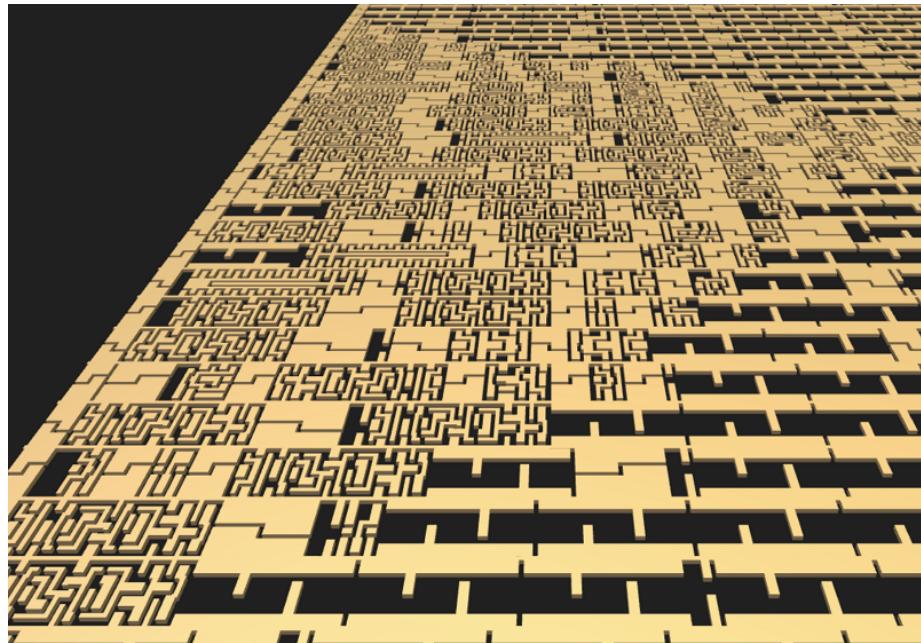


Figure 18: picture

- Author Wallace Everest
- Description Non-restoring square-root algorithm
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware Connect unsigned output to logic analyzer

## How it works

7-bit input, 4-bit output, unsigned

## How to test

Apply 1 Hz sine wave to unsigned input

## IO

#	Input	Output
0	io_in(0) => clk	io_out(0) => segment a
1	io_in(1) => data(0)	io_out(1) => segment b
2	io_in(2) => data(1)	io_out(2) => segment c
3	io_in(3) => data(2)	io_out(3) => segment d

#	Input	Output
4	io_in(4) => data(3)	io_out(4) => segment e
5	io_in(5) => data(4)	io_out(5) => segment f
6	io_in(6) => data(5)	io_out(6) => segment g
7	io_in(7) => data(6)	io_out(7) => none

# GOL-Cell

- Author Shaos
- Description Game of Life Cell
- GitHub repository
- Wokwi
- Extra docs
- Clock 0 Hz
- External hardware 8 neighbours and current state need to go in 2 stages using 5 inputs

## How it works

Calculate survive/die decision based on number of neighbours and current state

## How to test

Change number of neighbours and see

## IO

#	Input	Output
0	clock	segment a
1	reset	segment b
2	half	segment c
3	input 0 or 5	segment d
4	input 1 or 6	segment e
5	input 2 or 7	segment f
6	input 3 or 8	segment g
7	input 4 or 9	inverted clock

# 7-channel PWM driver controlled via SPI bus

- Author Ivan Krasin
- Description PWM driver with 7 channels and 256 PWM levels from 0 to 1
- GitHub repository
- HDL
- Extra docs
- Clock 1000 Hz
- External hardware

## How it works

uses a 8-bit counter to drive PWM on 7 output channels. Each channel is controlled by a dedicated 8-bit register that specifies its PWM level: 0 means always off, 1 is for 1/255 on, 5 is for 5/255 on and 255 is 255/255 (always on)

## How to test

after reset, all output pins will be low. Use SPI writes with register addresses (0..6) to set 8-bit PWM levels. The corresponding pin will start oscillating between 0 and 1 according to the clock and the set level.

## IO

#	Input	Output
0	clock	out0
1	reset	out1
2	cs	out2
3	sclk	out3
4	mosi	out4
5	reserved	out5
6	reserved	out6
7	reserved	miso

## hex shift register

- Author Eric Smith
- Description six 40-bit shift registers
- GitHub repository
- HDL
- Extra docs
- Clock Hz
- External hardware

## How it works

Six 40-bit shift registers. A multiplexer selects input data or recirculating output data.

## How to test

on each clock n, six bits are shifted in, and the six bits that were input at clock n-4 are output

## IO

#	Input	Output
0	clk	none
1	recirc	none
2	data_in[0]	data_out[0]
3	data_in[1]	data_out[1]
4	data_in[2]	data_out[2]
5	data_in[3]	data_out[3]
6	data_in[4]	data_out[4]
7	data_in[5]	data_out[5]

# Technical info

## Scan chain

All 498 designs are joined together in a long chain similar to JTAG. We provide the inputs and outputs of that chain (see pinout below) externally, to the Caravel logic analyser, and to an internal scan chain driver.

The default is to use an external driver, this is in case anything goes wrong with the Caravel logic analyser or the internal driver.

The scan chain is identical for each little project, and you can read it here.

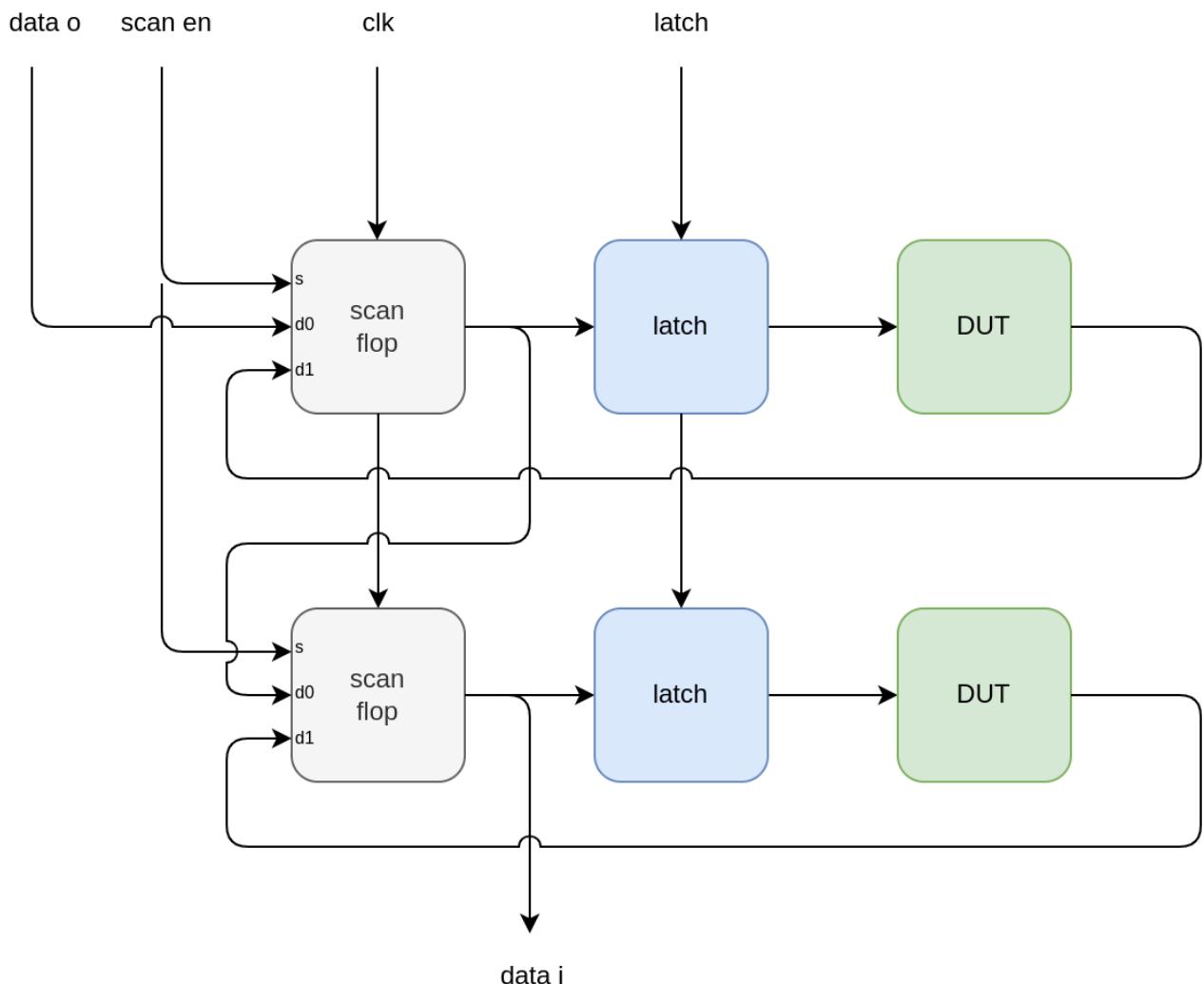


Figure 19: block diagram

## Updating inputs and outputs of a specified design

A good way to see how this works is to read the FSM in the scan controller. You can also run one of the simple tests and check the waveforms. See how in the scan chain verification doc.

- Signal names are from the perspective of the scan chain driver.
- The desired project shall be called DUT (design under test)

Assuming you want to update DUT at position 2 (0 indexed) with inputs = 0x02 and then fetch the output. This design connects an inverter between each input and output.

- Set scan\_select low so that the data is clocked into the scan flops (rather than from the design)
- For the next 8 clocks, set scan\_data\_out to 0, 0, 0, 0, 0, 0, 1, 0
- Toggle scan\_clk\_out 16 times to deliver the data to the DUT
- Toggle scan\_latch\_en to deliver the data from the scan chain to the DUT
- Set scan\_select high to set the scan flop's input to be from the DUT
- Toggle the scan\_clk\_out to capture the DUT's data into the scan chain
- Toggle the scan\_clk\_out another 8 x number of remaining designs to receive the data at scan\_data\_in

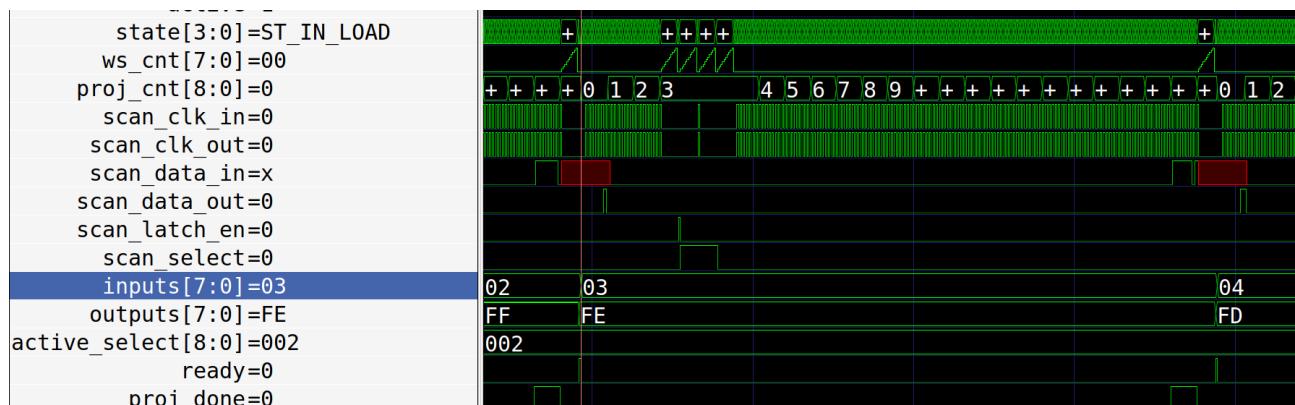


Figure 20: update cycle

#### *Notes on understanding the trace*

- There are large wait times between the latch and scan signals to ensure no hold violations across the whole chain. For the internal scan controller, these can be configured (see section on wait states below).
- The input looks wrong (0x03) because the input is incremented by the test bench as soon as the scan controller captures the data. The input is actually 0x02.
- The output in the trace looks wrong (0xFE) because it's updated after a full refresh, the output is 0xFD.

## Clocking

Assuming:

- 100MHz input clock
- 8 ins & 8 outs

- 2 clock cycles to push one bit through the scan chain (scan clock is half input clock rate)
- 500 designs
- scan controller can do a read/write cycle in one refresh

So the max refresh rate is  $100\text{MHz} / (8 * 2 * 500) = 12500\text{Hz}$ .

## Clock divider

A rising edge on the set\_clk\_div input will capture what is set on the input pins and use this as a divider for an internal slow clock that can be provided to the first input bit.

The slow clock is only enabled if the set\_clk\_div is set, and the resulting clock is connected to input0 and also output on the slow\_clk pin.

The slow clock is synced with the scan rate. A divider of 0 mean it toggles the input0 every scan. Divider of 1 toggles it every 2 cycles. So the resultant slow clock frequency is  $\text{scan\_rate} / (2 * (N+1))$ .

See the test\_clock\_div test in the scan chain verification.

## Wait states

This dictates how many wait cycle we insert in various state of the load process. We have a sane default, but also allow override externally.

To override, set the wait amount on the inputs, set the driver\_sel inputs both high, and then reset the chip.

See the test\_wait\_state test in the scan chain verification.

## Pinout

PIN	NAME	DESCRIPTION
20:12	active_select	9 bit input to set which design is active
28:21	inputs	8 inputs
36:29	outputs	8 outputs
37	ready	goes high for one cycle everytime the scanchain is loaded
10	slow_clk	slow clock from internal clock divider
11	set_clk_div	enable clock divider
9:8	driver_sel	which scan chain driver: 00 = external, 01 = internal
21	ext_scan_clk_out	for external driver, clk input

```
22      ext_scan_data_out    data input
23      ext_scan_select      scan select
24      ext_scan_latch_en    latch
29      ext_scan_clk_in     clk output from end of chain
30      ext_scan_data_in    data output from end of chain
```

## Instructions to build GDS

To run the tool locally or have a fork's GitHub action work, you need the GH\_USERNAME and GH\_TOKEN set in your environment.

GH\_USERNAME should be set to your GitHub username.

To generate your GH\_TOKEN go to <https://github.com/settings/tokens/new> . Set the checkboxes for repo and workflow.

To run locally, make a file like this:

```
export GH_USERNAME=<username>
export GH_TOKEN=<token>
```

And then source it before running the tool.

## Fetch all the projects

This goes through all the projects in project\_urls.py, and fetches the latest artifact zip from GitHub. It takes the verilog, the GL verilog, and the GDS and copies them to the correct place.

```
./configure.py --clone-all
```

## Configure Caravel

Caravel needs the list of macros, how power is connected, instantiation of all the projects etc. This command builds these configs and also makes the README.md index.

```
./configure.py --update-caravel
```

## Build the GDS

To build the GDS and run the simulations, you will need to install the Sky130 PDK and OpenLane tool. It takes about 5 minutes and needs about 3GB of disk space.

```
export PDK_ROOT=<some dir>/pdk
export OPENLANE_ROOT=<some dir>/openlane
```

```
cd <the root of this repo>
make setup
```

Then to create the GDS:

```
make user_project_wrapper
```

## Changing macro block size

After working out what size you want:

- adjust configure.py in CaravelConfig.create\_macro\_config().
- adjust the PDN spacing to match in openlane/user\_project\_wrapper/config.tcl:
  - set ::env(FP\_PDN\_HPITCH)
  - set ::env(FP\_PDN\_HOFFSET)

# Verification

We are not trying to verify every single design. That is up to the person who makes it. What we want is to ensure that every design is accessible, even if some designs are broken.

We can split the verification effort into functional testing (simulation), static tests (formal verification), timing tests (STA) and physical tests (LVS & DRC).

See the sections below for details on each type of verification.

## Setup

You will need the GitHub tokens setup as described in INFO.

The default of 498 projects takes a very long time to simulate, so I advise overriding the configuration:

```
# fetch the test projects
./configure.py --test --clone-all
# rebuild config with only 20 projects
./configure.py --test --update-caravel --limit 20
```

You will also need iVerilog & cocotb. The easiest way to install these are to download and install the oss-cad-suite.

## Simulations

- Simulation of some test projects at RTL and GL level.
- Simulation of the whole chip with scan controller, external controller, logic analyser.
- Check wait state setting.
- Check clock divider setting.

## Scan controller

This test only instantiates user\_project\_wrapper (which contains all the small projects). It doesn't simulate the rest of the ASIC.

```
cd verilog/dv/scan_controller
make test_scan_controller
```

The Gate Level simulation requires scan\_controller and user\_project\_wrapper to be re-hardened to get the correct gate level netlists:

- Edit openlane/scan\_controller/config.tcl and change NUM\_DESIGNS=498 to NUM\_DESIGNS=20.
- Then from the top level directory:  
`make scan_controller make user_project_wrapper`
- Then run the GL test  
`cd verilog/dv/scan_controller make test_scan_controller_gl`

## **single**

Just check one inverter module. Mainly for easy understanding of the traces.

```
make test_single
```

## **custom wait state**

Just check one inverter module. Set a custom wait state value.

```
make test_wait_state
```

## **clock divider**

Test one inverter module with an automatically generated clock on input 0. Sets the clock rate to 1/2 of the scan refresh rate.

```
make test_clock_div
```

## **Top level tests setup**

For all the top level tests, you will also need a RISCV compiler to build the firmware.

You will also need to install the ‘management core’ for the Caravel ASIC submission wrapper. This is done automatically by following the PDK install instructions.

## **Top level test: internal control**

Uses the scan controller, instantiated inside the whole chip.

```
cd verilog/dv/scan_controller_int
make coco_test
```

## **Top level test: external control**

Uses external signals to control the scan chain. Simulates the whole chip.

```
cd verilog/dv/scan_controller_ext  
make coco_test
```

## **Top level test: logic analyser control**

Uses the RISCV co-processor to drive the scanchain with firmware. Simulates the whole chip.

```
cd verilog/dv/scan_controller_la  
make coco_test
```

## **Formal Verification**

- Formal verification that each small project's scan chain is correct.
- Formal verification that the correct signals are passed through for the 3 different scan chain control modes.

## **Scan chain**

Each GL netlist for each small project is proven to be equivalent to the reference scan chain implementation. The verification is done on the GL netlist, so an RTL version of the cells used needed to be created. See here for more info.

## **Scan controller MUX**

In case the internal scan controller doesn't work, we also have ability to control the chain from external pins or the Caravel Logic Analyser. We implement a simple MUX to achieve this and formally prove it is correct.

## **Timing constraints**

Due to limitations in OpenLane - a top level timing analysis is not possible. This would allow us to detect setup and hold violations in the scan chain.

Instead, we design the chain and the timing constraints for each project and the scan controller with this in mind.

- Each small project has a negedge flop flop at the end of the shift register to reclock the data. This gives more hold margin.

- Each small project has SDC timing constraints
- Scan controller uses a shift register clocked with the end of the chain to ensure correct data is captured.
- Scan controller has its own SDC timing constraints
- Scan controller can be configured to wait for a programmable time at latching data into the design and capturing it from the design.
- External pins (by default) control the scan chain.

## Physical tests

- LVS
- DRC
- CVC

### LVS

Each project is built with OpenLane, which will check LVS for each small project. Then when we combine all the projects together we run a top level LVS & DRC for routing, power supply and macro placement.

The extracted netlist from the GDS is what is used in the formal scan chain proof.

### DRC

DRC is checked by OpenLane for each small project, and then again at the top level when we combine all the projects.

### CVC

Mitch Bailey' CVC checker is a device level static verification system for quickly and easily detecting common circuit errors in CDL (Circuit Definition Language) netlists. We ran the test on the final design and found no errors.

- See the paper here.
- Github repo for the tool: <https://github.com/d-m-bailey/cvc>

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## Team

Tiny Tapeout would not be possible without a lot of people helping. We would especially like to thank:

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